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THE MEASUREMENT OF GASES.

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THE measurement of gases forms a necessary part of many scientific and commercial operations. Perhaps the most common case has to do with the rate of flow in a pipe. It is generally required to ascertain the number of "standard cubic feet" passing in a given time; this meaning the amount of "stuff" or the weight of gas passing per unit of time. The contents of a standard cubic foot are determined by the assumed standards of temperature and pressure used in defining the unit of measurement. Scientific data on gases are usually referred to the freezing temperature of water and to the mean barometric pressure. Common commercial standards of temperature and pressure in gas measurement are 60 degrees F. and 30 inches of mercury, respectively.

The object of this paper is to describe experiments with several forms of gas meters and to show how the results have been used in connection with the development of an entirely new form of meter. Aside from the use of the results in connection with the development work, they are of considerable interest from a scientific standpoint, because they are all based upon accepted scientific principles and their agreement forms an interesting

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confirmation of several theories. The experiments show that, given proper conditions, very satisfactory results can be obtained in measuring gas with any of the types of meter used during the development work, and with the new type of meter it has been possible to arrive at a very interesting check upon the accuracy of the older types. The comparative advantages and disadvantages in the operation of each type depend upon the particular conditions under which measurement is made.

The practical result which has been attained in the investigation forming the basis of this paper is the development of a meter with which continuous measurement can be carried on automatically under commercial conditions with the same degree of accuracy as is obtainable with the other types of meters by laboratory methods requiring the greatest refinement in instruments and in observations.

THE FLOW OF GASES THROUGH PIPE LINES.

When gas making was first undertaken on a commercial scale it became necessary to determine the conditions governing the rate of flow in pipes. A number of principles were enunciated by Dr. Pole and published about 1851, together with what is known as Pole's formula. An excellent discussion of Dr. Pole's work is found in a book by Mr. Walter Hole on the "Distribution of Gas," published by John Allan & Company, London. The following statement of Dr. Pole's principles and of the accompanying formulæ for flow in pipes is taken from Mr. Hole's book:

"Dr. Pole's principles:

"1. That the friction of a fluid passing through a pipe is independent of the hydrostatic pressure to which the fluid is subjected—in other words, the friction of a column of water is no greater at 100 pounds pressure than at a pressure of 1 pound, other things being equal.

"2. That the friction is strictly proportional to the area of the rubbing surface. That is to say, if the length of a pipe is doubled the friction will be doubled also. If, therefore, l = length of pipe, c = internal circumference, and F = friction, F is proportional to lc.

"3. That the friction varies with the velocity, but the ratio is not very well determined. Approximately it varies as the

square of the mean velocity. The particles of gas or water at the centre of a pipe move faster than those at the circumference, owing to the retarding action of friction. The mean velocity, therefore, is such that, being multiplied into the area of the pipe, it gives the quantity passing through. If the velocity is doubled, then friction is increased fourfold, or F is proportional to V^2.

"4. That friction is proportional to the specific gravity of the fluid, or will vary as S. Friction also is absolutely independent of the position of the pipe, other things being equal. It makes no difference whatever to friction whether the pipes are made to assume a horizontal, vertical, or inclined position. It is the same in each case."

Following out the reasoning briefly given above, Dr. Pole ultimately arrives at a working formula, which is as follows:

$$V = 1350 d^2 \sqrt{\frac{p\,d}{s\,l}}$$

where

v = volume of gas discharged in cubic feet per hour.
d = diameter of pipe in inches.
p = pressure in inches of water above atmosphere.
s = specific gravity of gas (air = 1).
l = length of main in yards,
and 1350 is a constant deduced from practical experiment.

According to Professor Unwin, the coefficient of friction varies from .0082 for a 2-inch main to .0063 for 4-inch, .0053 for 8-inch and .0048 for 18-inch. Dr. Pole assumed a uniform value of .0060.

The following laws are derived from the formula:

(1) By increasing the pressure fourfold the discharge is doubled.

(2) By increasing the length fourfold the discharge is halved.

(3) By increasing the length fourfold, four times the pressure will be necessary if the discharge is to remain the same. And as a further deduction from this,

(4) The pressure necessary to the discharge of a stated quantity of gas through a pipe of given diameter varies directly as the length of the pipe.

(5) By decreasing the length to one-fourth the discharge is doubled.

(6) By increasing the diameter four times the discharge is increased thirty-two times.

(7) In this equation the pressure is understood to be that necessary to force the gas through the pipe and the latter is assumed to discharge into the air at atmospheric pressure. If the discharge is to take place at a given pressure above atmosphere, then that pressure must be added to the pressure necessary to the discharge and applied at the inlet of the pipe.

Various modifications are necessary to allow for pipes other than straight and level, for bends, varying back pressure, etc.

The following modification of this formula by Professor Unwin takes account of sloping mains:

$$Q = \frac{\pi}{4} d^2 v$$

$$v = 4.012 \sqrt{\frac{d\,h}{F\,l}}$$

$$h = 780 \frac{y_1 - y_2}{s} + \left(z_1 - z_2\right)\left(1 - \frac{1}{s}\right)$$

where

Q = discharge in cubic feet per second.
d = diameter of pipe in feet.
v = velocity in feet per second.
h = head in feet of gas.
y_1 = initial pressure in feet of water.
y_2 = outlet pressure in feet of water.
z_1 = initial position with respect to horizontal datum line.
z_2 = final position with respect to horizontal datum line.
F = coefficient of friction.
s = specific gravity of gas.
l = length of pipe in feet.

Although these formulæ give fairly reliable results when applied to the discharge of gases of low pressures, they do not take into account the varying densities and volumes when the gases are subjected to higher pressures, such as those encountered in natural gas work. Taking into account these changes in volume and density, Professor Unwin arrived at the following equations:

$$Q = \frac{\pi}{4} d^2 u_2 = \frac{\pi}{4} \frac{p_1}{p_2} d^2 u_1$$

where

Q = discharge in cubic feet per second measured at the pressure p_2.
d = diameter of the pipe in feet.
u_1 = the velocity in feet per second at the inlet of the pipe.
u_2 = the velocity in feet per second at the outlet of the pipe.
p_1 = the absolute pressure at the inlet of the pipe.
p_2 = the absolute pressure at the outlet of the pipe.

The value of u_1 may be obtained from the following formula:

$$u_1 = 468 \sqrt{\frac{d}{Fsl} \frac{p_1^2 - p_2^2}{p_1^2}}$$

where

d = diameter of the pipe in feet.
l = length of pipe in feet.
s = specific gravity of the gas.
F = coefficient of friction.
p_1 = absolute pressure at the inlet of the pipe.
p_2 = absolute pressure at the outlet of the pipe,

and $u_2 = \frac{p_1}{p_2} u_1$

The demand for a reliable and convenient formula for use in natural gas work in America has brought forth the following representative formulæ:

Professor Lowe's Formula:

$$Q = C \sqrt{\frac{d^5 (p_1 - p_2)(p_1 + 14.7)}{0.0761 \times s \times l \times 14.7}}$$

where

Q = discharge of gas in cubic feet per minute at atmospheric pressure.
C = a constant depending on the size of the pipe, varying from 52.7 for a 2-inch pipe to 63.2 for a 24-inch.
p_1 = initial gauge pressure in pounds.
p_2 = final gauge pressure in pounds.
d = diameter of pipe in inches.
l = length of pipe in feet.
0.0761 = weight of one cubic foot of air at atmospheric pressure.
s = specific gravity of the gas.

Oliphant's Formula:

$$Q = 42\,a \sqrt{\frac{p_1^2 - p_2^2}{l}}$$

where

Q = quantity discharged in cubic feet per hour.
p_1 = absolute pressure in pounds per square inch at the inlet.
p_2 = absolute pressure in pounds per square inch at the outlet.
l = length of main in miles.
a is a multiplier, varying from 16.5 for a 3-inch pipe to 2055.0 for a 20-inch pipe.

The Pittsburg Formula:

$$Q = 3450 \sqrt{\frac{d^5(p_1^2 - p_2^2)}{l}} \quad \text{when } s = 0.60,$$

and Coxe's Formula:

$$Q = 41.3 \sqrt{\frac{d^5(p_1^2 - p_2^2)}{L}} \quad \text{when } s = 0.65.$$

In these formulæ,

Q = discharge in cubic feet per hour.
p_1 and p_2 = absolute initial and terminal pressure, respectively, in pounds per square inch.
d = internal diameter of pipe in inches.
L = length of main in miles.
l = length of main in feet.
s = specific gravity (air = 1).

The following table shows a comparison of results computed from these various formulæ with measured results. The measured results given were obtained by Mr. George Helps, of Nuneaton, and are for discharge through a 3-inch main three miles long from the three different inlet pressures to atmospheric pressure at the outlet:

	Discharge in Cubic Feet per Hour.		
	5 lbs. Gauge Pressure	10 lbs. Gauge Pressure	18 lbs. Gauge Pressure
Discharge by measurement,	5,000	10,000	18,000
By Formulæ:			
Professor Unwin,	4,852	7,429	11,268
Professor Lowe,	5,520	8,700	13,500
Pittsburg,	6,226	9,629	14,136
Oliphant,	5,287	8,011	11,773
Coxe	5,541	8,360	12,318

From a comparison of the results obtained with the different formulæ it is seen that they can be used for rough approxima-

tions only. It is quite probable that the measured results given are in error, but it is very difficult to obtain results to check these formulæ on account of the irregular shapes of pipe lines, the presence of fittings, and the difficulty of obtaining steady flow throughout a long pipe for a sufficient time. For the same reason it would be difficult to make use of the formulæ for the practical measurement of flow through pipe lines, even if they were correct for steady flow through straight pipes.

Mr. Forrest M. Towl has made some very thorough and interesting investigations of the pressure drops in a long natural gas line from which he has derived reliable coefficients for a formula similar to the "Pittsburg" formula. In these tests the rate of flow was carefully measured as well as the pressures at various points in the line, and great pains were taken to obtain steady flow throughout the pipe.

It is evident that it would be very unsatisfactory to use gas transmission lines as meters for measuring the flow of gas through them by observing the physical properties of the entering and exit gas, and it would be impossible to make use of such lines for reliable commercial measurement unless each line was very thoroughly calibrated after being installed and the flow of gas was kept steady. Some form of meter must be inserted in the line, and from the above consideration it would seem necessary, if accurate results are to be obtained, that the meter be comparatively short, so that the portion of the gas passage between the sections at which physical observations are made may have no effect upon the flow other than that intended.

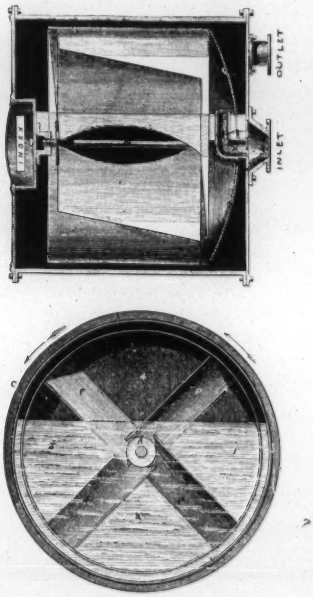
METERS.

A quite general classification of meters includes two main types: volumetric meters and velocity meters.

Volumetric meters include what are known as dry meters, operating on the general principle of a bellows, and "wet meters." The latter are built in large sizes for use at gas works in measuring the gas as made, before being passed for storage to the holders. These meters are known as station meters. Their construction is, in general, that of a drum revolving within a large cylindrical tank which is approximately two-thirds filled with water. The revolving drum consists of a shaft carrying three or four partitions arranged in a spiral form. These partitions emerge

in turn from the water as the shaft revolves, and each forms with the water a water-sealed compartment, which alternately receives and delivers gas. The drum receives its motion from the pressure of the gas itself as exerted upon its surfaces. The general construction of a wet meter is illustrated in Fig. 1.

FIG. 1



Longitudinal and transverse sectional views of wet displacement meter.

Gas holders have at times been used for measuring gas, but temperatures in a large holder vary so widely, due to the heat of the sun and other causes, that holder tests are in general quite unreliable. However, small holders, having a capacity of 5 to 10 cubic feet, can be very satisfactorily used for checking the accuracy of other volumetric meters. These small holders are known as meter provers.

A well-known form of the velocity type is the Rotary Meter,

which works upon the anemometer principle, the amount of gas passing per unit of time being taken as proportional to the speed at which the vanes revolve.

These meters are all more or less satisfactory for commercial measurement under certain limited conditions. This paper, however, deals with meters of three types differing from the above, and based upon fundamental principles; and aims to show the comparative value of the results that can be obtained with them under similar conditions of refinement in methods of operation. It also aims to describe the methods of obtaining these results.

The three types of meter referred to in the following are: the Pitot tube, which depends for its operation upon fundamental principles of hydraulics; the Venturi meter, which depends upon thermodynamic principles involving the ratio of specific heats at constant pressure and constant volume, the ratio of cross sectional areas of throat and pipe, and the ratio of pressures in throat and pipe respectively; and the heat or electric meter, based upon a very simple principle of thermodynamics involving the specific heat of the gas at constant pressure,—in which the temperature of the gas is increased through a known range by a measurable amount of heat.

THE PITOT TUBE.

The Pitot tube affords a means of measuring the velocity of air or gas through a pipe at any given point in the pipe section. In its simplest form it consists of two small tubes inserted in the pipe line, one having an opening pointed up stream and communicating to one end of a U-tube the pressure due to velocity head in addition to the static pressure in the pipe; the other having an opening at right angles to the direction of flow and communicating to the opposite side of the U-tube the static pressure only. The difference between these two pressures is the pressure due to velocity alone, and from this the velocity of the gas in the pipe can be computed by means of the formula, $v^2 = 2gh$ where h is the static head necessary to give to the air or gas a velocity of v feet per second. From a knowledge of the cross sectional area of the pipe and the density of gas at the observed pressure and temperature, the quantity passing per unit of time can be computed.

The velocity of the gas flowing through a pipe is not the

same at all points in the section. It falls off gradually from the centre outward and very rapidly near the inner skin of the pipe. In order to obtain accurate results with Pitot tubes without exploring the pipe at several different depths, and averaging the readings by the zone method, it is necessary to "standardize" the tube and the pipe together and find the depth at which the tube will indicate the mean velocity; that is, a Pitot tube will not necessarily give consistent readings if placed in a given position in pipes of different sizes, different conditions of surface, etc. The tube must be located with special reference to the size, shape, and condition of the pipe with which it is to be used. Great care must be taken that the openings through which the pressures are communicated to the U-tube are properly placed with respect to the direction of flow, and they must be kept free from deposits.

THE VENTURI METER.

The Venturi meter consists of a throat or gradually contracted portion of the passage which causes a decrease in pressure and an increase in velocity of the gas flowing through it.

Let A_1 = area of the upstream section.
A_2 = area of throat.
P_1 = pressure at upstream side.
P_2 = pressure at throat.
G_1 = weight of gas at upstream section.
n = ratio of specific heats at constant pressure and constant volume respectively.
V_2 = velocity of gas at the throat.

By equating the loss in potential energy to the increase in kinetic energy, it is found that

$$V_2 = \left(\frac{P_1}{G_1}\right)^{\frac{1}{2}} \left(\frac{2gn}{n-1}\right)^{\frac{1}{2}} \left\{ \frac{1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2 \left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}} \right\}^{\frac{1}{2}}$$

and if Q is the quantity flowing,

$$Q = A_2 V_2 G_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

The observations necessary to obtain results with the Venturi meter are the pressure of the gas or air at the upstream

side, the difference in pressure between the upstream side and the throat, and the temperature at the upstream side.

As will be seen from the readings taken on the test herein described, it is very often necessary, with both the Venturi meter and the Pitot tube, to read very small differences of pressure. In order to determine these accurately it is necessary to read the water columns with either a micrometer gauge or with a differential (inclined) water column. Pulsations in the gas main interfere with taking accurate readings even with the precision instruments used in these tests, but such precaution as it was possible to use has given results that mutually agree within a small percentage. Deposits on the throat of the Venturi meter must be avoided and for both the Pitot tube and Venturi meter a considerable length of approach should be provided in order to insure a steady flow, free from eddies and pulsations.

THE ELECTRIC METER.

The "heat," or "electric" meter is based upon the principle of heating the air or gas through a known range of temperature and measuring the energy required to cause the change in temperature. This measured energy is proportional to the weight of gas flowing. Electric energy is used as a source of heat because it can be so conveniently and accurately applied and measured. Electrical resistance thermometers are used to regulate the temperature range through which the gas is heated, because with thermometers of such type very small differences of temperature can be accurately and easily determined.

If E is the amount of energy required to raise the temperature of Q units of weight of gas or air through t degrees, and if s is the specific heat of the unit of weight at constant pressure, then

$$Q = \frac{E}{t \times s}$$

In this type of meter the heater unit has its resistance material evenly distributed over the section of the passage so that all of the gas is heated. The resistance thermometer screens are likewise evenly distributed over the passage so that the temperatures of the gas are accurately integrated. This meter is therefore independent of the variation in velocity of the gas at different parts of the pipe and the gas does not need to approach

it through long lengths of straight pipe. Rapid fluctuations in flow do not interfere with its accuracy on account of the slight heat "capacity" of the thermometers, which causes a time lag of a few seconds in the operation of the controlling mechanism. Since the measurements involved in this meter are all those of electrical quantities, the observations can be made very conveniently with the greatest degree of refinement, and at any reasonable distance from the meter itself. Deposits on the inner passages of the meter or upon the heater or thermometer units have no effect upon the accuracy of the meter and can only cause the units to be somewhat slower in their action than when perfectly clean.

Since all three of these methods of measurement are based directly upon fundamentally correct theories, they should all agree as to results when properly applied, in a given pipe, to the measurement of a given flow of gas or air. One of the purposes of this paper is to show how this has been proven by tests made in the Engineering Laboratory of the University of Wisconsin and also by very complete comparative tests of commercial types of the meters under conditions of regular operation.

COMPARATIVE LABORATORY TESTS.

The three meters in laboratory form were arranged in series in a pipe line through which air was passed by means of a fan, as shown in Figs. 2 and 3. The fan was driven by a motor and the rate of flow of air was regulated by the speed of the fan.

Fig. 4 shows a detail of the Pitot tube. The opening at *A* points upstream and communicates through the tube *A* the pressure and velocity head, while small holes or slots (both in these experiments), opening at right angles to the direction of flow, communicate the pressure head through tube *B*. The difference in these two heads was observed in inches of water on an Ellison inclined pressure gauge graduated to hundredths of an inch. The readings were estimated to thousandths of an inch.

The shank *C* of which the pressure tubes formed a part passed through a bushing attached to the outside of the pipe, making it possible to slide the tube to any point between the centre of the pipe and its inside surface. The position of the Pitot tube with respect to the centre of the pipe could be read from a scale on the shank. The velocity head was determined at one-

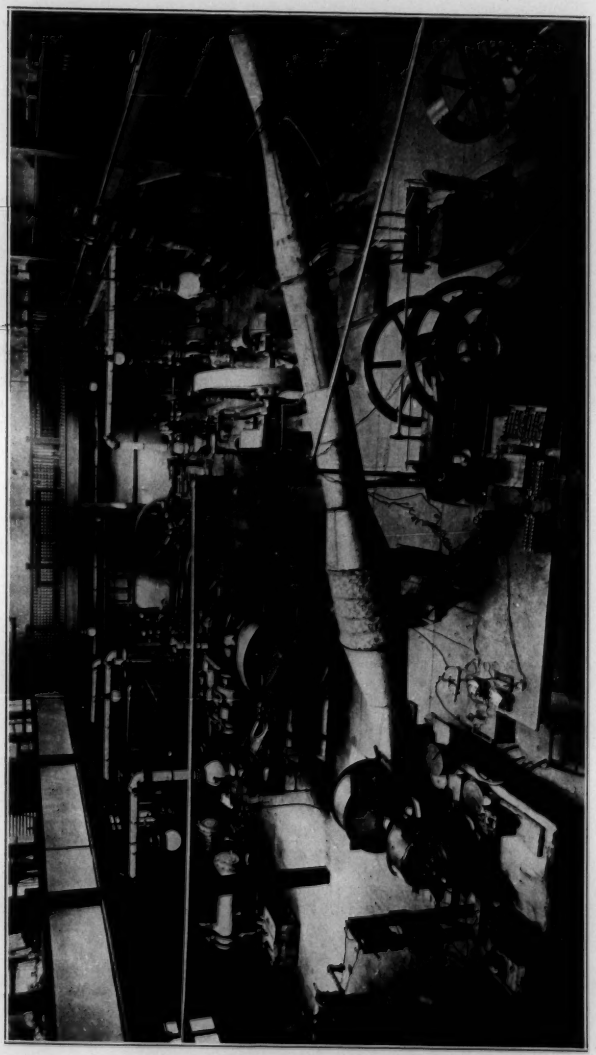
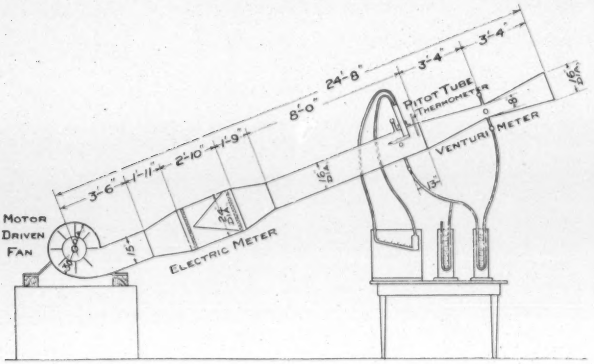


FIG. 2.

Apparatus for air tests; Gas Engineering Laboratory, University of Wisconsin.

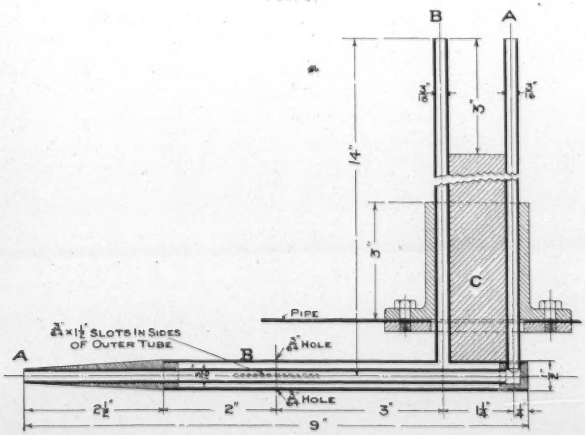
inch intervals from the centre of the pipe to five inches out and at one-half inch intervals from this point to within one-half inch

FIG. 3.



Diagrammatic sketch of apparatus showing general dimensions.

FIG. 4.

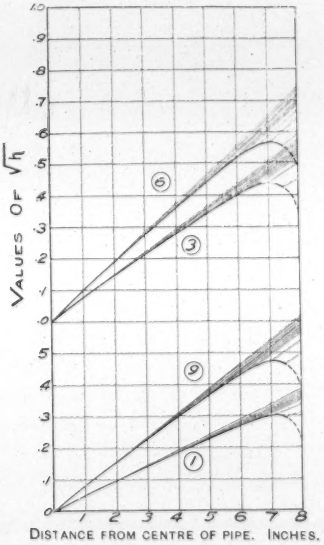


PITOT TUBE.

of the inner surface. From these readings the mean value of h was determined as follows:

Let a horizontal line, Figs. 5 and 6, represent the radius of the pipe. On this line lay off points to a suitable scale representing the distances from the centre of the pipe at which readings of h were observed, and erect perpendiculars at these points. On the perpendicular representing the inner surface of the pipe lay off to some suitable scale values of $\sqrt{h}$. Join the points representing values of $\sqrt{h}$ to the point on the horizontal line rep-

FIG. 5.



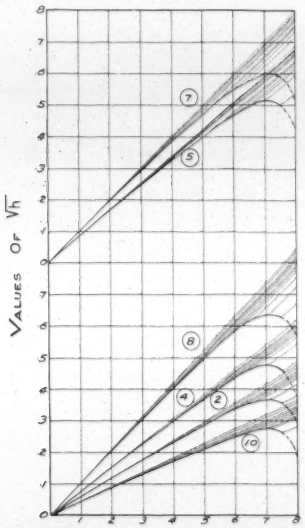
Graphical method of determining mean velocity head for Pitot tube.

resenting the centre of the pipe. The intersections of the resulting slanting lines from each of the points representing $\sqrt{h}$ with the perpendiculars representing the positions at which the corresponding values of $\sqrt{h}$ were read are points through which a smooth curve can be traced. The area under the curve may now be determined, and from this may be found the altitude of a triangle having the same area and the same base as the irregular figure. This altitude reduced to the proper scale will give the

mean value of $\sqrt{h}$ from which the mean value of velocity may be computed. This method was devised by Professor G. H. Davis, of the University of Wisconsin.

It was found by experiments made with this particular Pitot tube and pipe that the mean value of h occurs at 0.83 of the distance from the centre of the pipe to the side. The mean line

FIG. 6.



Graphical method of determining mean velocity head for Pitot tube.

and the curves representing variation of velocity from the centre of the pipe to the side are shown in Fig. 7.

The mean velocity in the pipe is calculated from the formula,— $V^2 = 2gh$. This mean velocity is in feet per second, h having been reduced to its equivalent in feet of air.

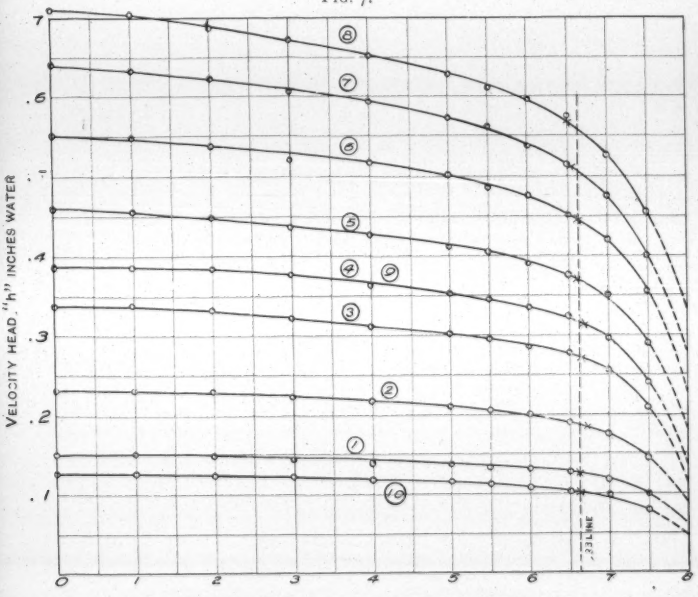
The pounds of air per hour then equal 3600 AVG, where

A = area of pipe in square feet,
V = velocity in feet per second,
G = weight of a cubic foot of the air as it passed through the pipe.

THE VENTURI METER.

The arrangement of the Venturi meter used in the tests is shown in Fig. 3. The pressure of the air on the upstream side was measured by means of a water column read by a micrometer scale to 1/500 of an inch. The difference in pressure between

FIG. 7.



PITOT TUBE.—VELOCITY HEAD "H" VS. DISTANCE FROM CENTRE OF PIPE.
Mean velocity head = .83 distance from centre of pipe.
X = location on curve of calculated mean velocity head.

throat and upstream side was measured on a differential water gauge graduated in tenths of inches which could be read accurately to hundredths of an inch. From the barometer reading and from the above two readings the absolute pressures at both upstream side and throat were found.

The values of the following terms,—

$$\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}, \quad \left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}, \quad \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}$$

which appear in the formula for velocity were determined from a set of carefully prepared curves giving values of these expressions for different values of the ratio of pressures, n representing the ratio of specific heats at constant pressure and constant volume respectively, and taken as 1.406.

The temperature of the air at the upstream pressure P_1 was read on a standard calibrated thermometer, and the readings reduced to absolute temperature in degrees F. The humidity of the air was determined by means of wet and dry bulb thermometers placed near the suction to the fan. The per cent. humidity was taken from tables by applying the observed temperature readings. From the steam tables of Messrs. Marks and Davis the vapor pressures at the various temperatures were noted. The product of vapor pressure and per cent. humidity gives the pressure in the air due to moisture, and the pressure due to dry air alone is found by deducting the vapor pressure from the total pressure P_1. The weight per cubic foot of dry air under the conditions noted was added to the computed weight of moisture present, the result giving the weight per cubic foot of air as it passed the Venturi meter.

The upstream section of the pipe was 16 inches in diameter and the throat section was 8 inches. The square of the ratio of throat to upstream area $\left(\frac{A_2}{A_1}\right)^2$ was found to equal 0.06262 after allowance was made for the presence of the Pitot tube in the pipe.

THE ELECTRIC METER.

The electric meter used in the test is shown diagrammatically in Fig. 8. Within the pipe is an electric heater unit between two electric thermometer units T_1 and T_2. The heater consists of spiral turns of bare resistance wire wound around a conical supporting frame so that heat is dissipated evenly over the section of the pipe. In the heater circuit is a rheostat for regulating the electrical energy supplied to the heater and instruments for measuring this energy.

The thermometer units consist of resistance wire evenly distributed over the section of the pipe, and of such material that their resistance increases when their temperature is increased. They form two arms of a Wheatstone bridge, the other two arms being fixed coils of wire that have a zero temperature

FIG. 8.

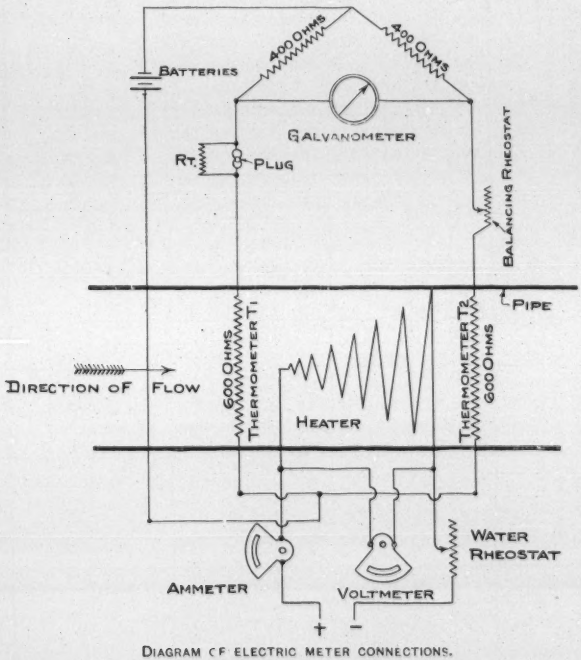


DIAGRAM OF ELECTRIC METER CONNECTIONS.

coefficient. Across the Wheatstone bridge is a galvanometer, and in series with one thermometer is a small rheostat for balancing the bridge. In series with the entrance thermometer is also a small resistance R_T, equal in value to the increase in resistance in the exit thermometer for a rise in temperature of about 2 degrees F. (in this particular case 2.024 degrees).

This temperature difference resistance is arranged so that it can be conveniently shorted out. The operation of this meter is as follows:

No. of Test		1	2	3	4	5	6	7	8		9	10	
Pitot Tube Readings Distance From Center of Pipe	.0	.150	.230	.336	.385	.460	.552	.640	.710		.385	.125	
	1.0	.150	.230	.336	.385	.455	.548	.632	.705		.385	.125	
	2.0	.148	.228	.330	.383	.448	.538	.622	.685		.378	.123	
	3.0	.143	.222	.320	.370	.435	.520	.605	.670		.365	.120	
	4.0	.138	.216	.310	.362	.425	.516	.592	.650		.357	.117	
	5.0	.136	.210	.300	.352	.410	.500	.572	.627		.348	.114	
	5.5	.133	.205	.294	.345	.405	.485	.562	.610		.340	.112	
	6.0	.131	.200	.285	.335	.390	.475	.538	.595		.332	.109	
	6.5	.128	.190	.277	.322	.375	.450	.515	.575		.320	.102	
	7.0	.117	.175	.255	.295	.350	.420	.475	.525		.292	.099	
	7.5	.100	.145	.208	.240	.290	.355	.400	.455		.248	.080	
Venturi Meter	(H_2O) Diff. in Press	1.57	2.60	4.15	4.56	5.40	6.74	7.90	8.80		4.60	1.36	
	Press	.43	.655	.93	1.085	1.20	1.52	1.765	2.07		1.15	.46	
	Temp.	82	83	84	85	85	87	89.5	91		90	85	
Fan	R.P.M.	450	565	680	740	800	897	956	1025		740	408	
Hydro-Meter	Wet	73.5	73.0	74.0	74.0	74.0	74.5	76.5	77.5		78.0	75.5	
	Dry	82.0	83.0	83.5	84.0	84.0	84.5	86.5	88.0		88.0	85.5	
	Temp.	79	80	81	81	81	82.5	86	87.5		87	83	
Electric Meter	Volts	55.5	62.4	68.5	71.5	74.0	78.5	80.5	84.0		71.4	52.4	
	Amps	22.0	24.7	27.2	28.5	29.5	31.2	32.0	33.3		28.3	21.0	
	Barometer	29.044	29.044	29.044	29.044	29.044	29.034	29.034	29.034		29.034	29.034	
	Temp.	79	79	79	79	79	79	79	79		79	79	

GENERAL LOG OF AIR TESTS.

University of Wisconsin, Gas Laboratory, June 2, 1911.

With air or gas flowing through the meter but with no energy in the heater, and with the temperature-difference resistance R_T shorted out, the two thermometers are brought to exact bal-

ance by means of the balancing rheostat and the galvanometer. Then the resistance R_T is cut in and sufficient electrical energy

VENTURI METER

NO. OF TEST	1	2	3	4	5	6	7	8		9	10
BAROM. ($^{LBS}/_{in^2}$)	14.2315	14.2315	14.2315	14.2315	14.2315	14.2315	14.2266	14.2266		14.2266	14.2266
P_1 (H_2O)	.430	.655	.930	1.085	1.200	1.520	1.765	2.070		1.150	.460
P_3 (MINUS) (H_2O)	1.140	1.945	3.220	3.485	4.200	5.220	6.135	6.730		3.450	.900
P_1 ($^{LBS}/_{in^2}$)	.0155	.0237	.0336	.0392	.0433	.0548	.0637	.0747		.0415	.0166
P_2 (MINUS) ($^{LBS}/_{in^2}$)	.0412	.0702	.1160	.1258	.1515	.1882	.2215	.2430		.1245	.0325
P_1 (ABS.)	14.2470	14.2552	14.2651	14.2707	14.2748	14.2863	14.2903	14.3013		14.2681	14.2332
P_2 (ABS.)	14.1903	14.1613	14.1155	14.1057	14.0800	14.0433	14.0051	13.9836		14.1021	14.1941
P_2/P_1	.996	.994	.991	.989	.987	.983	.981	.978		.988	.997
HUMIDITY 63%											
TEMP. AIR °F	82	83	84	85	85	87	895	91		90	85
WT. CU FT. DRY AIR	.07327	.07314	.07300	.07287	.07287	.07261	.07220	.07207		.07221	.07287
WT. CU FT. VAPOR	.00167	.00172	.00178	.00183	.00183	.00195	.00210	.00220		.00213	.00183
G_1 ($^{LBS}/_{CU\,FT_1}$)	.07432	.07422	.07412	.07402	.07402	.07384	.07352	.07345		.07355	.07402
A_2 ($^{0\,FT_1}$)	.349	—	—	—	—	—	—	—		—	—
$\sqrt{\frac{2gn}{n-1}}$	14.898	—	—	—	—	—	—	—		—	—
$(P_2/P_1)^{\frac{1}{n}}$	.9971	.9956	.9935	.9920	.9906	.9878	.9863	.9842		.9912	.9978
$(P_2/P_1)^{\frac{2}{n}}$	.9940	.9912	.9870	.9840	.9812	.9755	.9724	.9682		.9825	.9955
$(P_2/P_1)^{\frac{n-1}{n}}$	.9988	.9982	.9973	.9967	.9961	.9949	.9944	.9934		.9964	.9991
$(A_2/A_1)^2$	.06262	—	—	—	—	—	—	—		—	—
$\sqrt{P_1/G_1}$ SINCE 144	166.0	166.4	166.6	166.9	167.0	167.1	167.3	167.5		167.2	166.3
$\sqrt{\frac{1-(P_2/P_1)^{\frac{n-1}{n}}}{1-(A_2/A_1)^2(P_2/P_1)^{\frac{2}{n}}}}$	.0358	.0438	.0537	.0593	.0645	.0735	.0773	.0839		.0619	.0310
Q (LBS PER HR)	8250	10400	12320	13600	14780	16870	17560	19000		14110	7130

$$Q\ (\text{lbs. per hr.}) = 3600\, A_2 G_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} \sqrt{\frac{2gn}{n-1}} \sqrt{\frac{P_1}{G_1}} \sqrt{\frac{1-\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{P_2}{P_1}\right)^{\frac{2}{n}}}}$$

CALCULATIONS FOR AIR TESTS.
University of Wisconsin, Gas Laboratory, June 2, 1911.

is supplied to the heater to bring the galvanometer to a balance again; that is, sufficient electrical energy is supplied to bring the

exit air or gas to a temperature two degrees higher than that of the entering gas, regardless of the absolute temperature of the entering gas. The measuring instruments in the heater circuit then indicate the energy required to raise the temperature of the air or gas through a known range.

ELECTRIC METER

No. OF TEST	1	2	3	4	5	6	7	8		9	10
WT. DRY AIR PER CU. FT.	0.7327	.07314	.07300	.07287	.07287	.07261	.07220	.07207		.07221	.07237
WT. WATER VAPOR PER CU. FT. OF AIR 63% SATURATION	.00105	.00108	.00112	.00115	.00115	.00123	.00132	.00138		.00134	.00115
SP. HT. DRY AIR LB.	0.2375										
SP. HT. VAPOR LB.	.048										
SP. HT. PER LB. OF AIR 63% SAT.	.2410	.2410	.2410	.2415	.2415	.2415	.2419	.2420		.2418	.2415
VOLTS	55.5	62.4	68.5	71.5	74.0	78.5	80.5	84.0		71.4	52.4
AMPERES	22.0	24.7	27.2	28.5	29.5	31.2	32.0	33.3		28.3	21.0
WATTS	1222	1541	1812	2039	2183	2448	2575	2797		2021	1100
LBS. AIR PER HR. WATTS × 3.412 SPEC. HT. × 2.0239	8550	10790	12670	14220	15230	17100	17950	19480		14100	7580

PITOT TUBE

No. OF TEST	1	2	3	4	5	6	7	8		9	10
MEAN $h(H_2O)$	.125	.187	.272	.315	.368	.444	.505	.558		.318	.100
MEAN h (FT. AIR)	8.75	13.10	19.10	21.42	25.85	31.25	35.70	39.58		21.42	7.03
MEAN VEL. (FT. PER SEC.) = $\sqrt{29h}$	23.70	29.00	35.00	37.18	40.75	44.80	47.90	50.45		37.18	21.25
WT. CU. FT. = G	.07432	.07422	.07412	.07402	.07402	.07384	.07352	.07345		.07355	.07402
LBS. AIR PER HR. = $3600\sqrt{29h}$ AG	8860	10310	13020	13820	15170	16650	17720	18610		13750	7900
A = AREA = 1.396 SQ. FT.											

CALCULATIONS FOR AIR TESTS.

University of Wisconsin, Gas Laboratory, June 2, 1911.

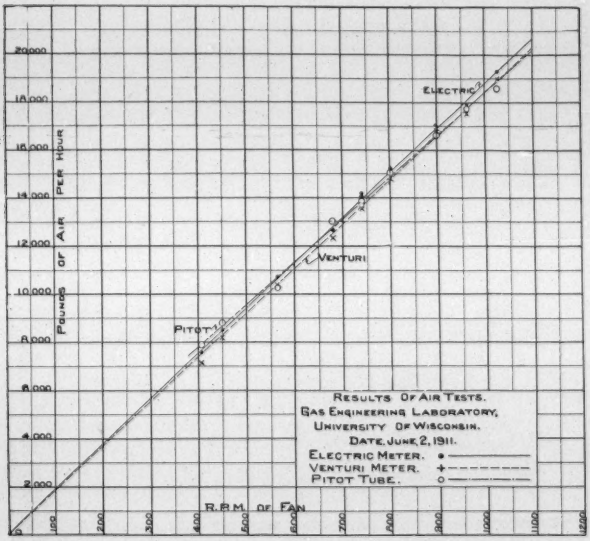
RESULTS.

Simultaneous readings were taken on the three meters at different fan speeds. Great care was necessary in reading the water columns of the Pitot and Venturi meters because of small fluc-

tuations in fan speed, but the observations were made with the greatest degree of refinement possible with the apparatus. The observations and computations are recorded in the following data sheets and the comparative results are plotted in Fig. 9.

The close agreement of the results obtained in the measurement of a common quantity by these three fundamental and independent methods of measurement, with independent observa-

FIG. 9.



tions taken for each, forms, from a scientific standpoint, a very interesting proof of the correctness of the several theories involved. The test also shows that any of the three meters will give satisfactory results, provided they are properly used under sufficiently favorable conditions, and provided the observations are made with a sufficient degree of refinement.

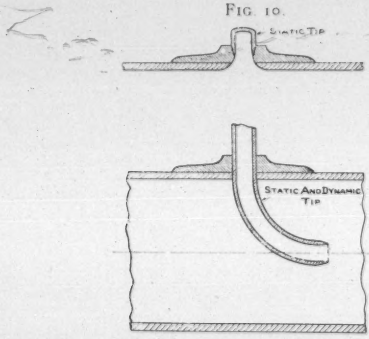
It is evident, however, that by the electric method results can be obtained directly from simple observations made with instruments of only moderate refinement that compare most favorably with those that can be obtained by the Pitot or Ven-

turi meters after laborious computations based on observations carefully taken from refined instruments.

THE COMMERCIAL MEASUREMENT OF GASES.

Although the wet and dry displacement meters and the rotary meters give satisfactory results for commercial purposes under some conditions of service, their application is very limited by conditions of pressure, temperature, capacity, etc., and there is a vast number of instances in which air and gases must be measured by some form of the meters described in the preceding

FIG. 10.



PITOT TUBE.

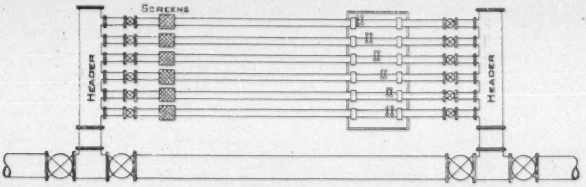
pages. It is in most cases highly desirable to use some form of meter that will give reliable results automatically under continuous service conditions, independently of fluctuations in pressure and temperature, and that will record the flow either on a graphical chart or on a totalizing dial, or both.

The Pitot tube has been very successfully applied to the measurement of high pressure natural gas where a comparatively small drop in pressure can always be made use of to increase the velocity of the gas through a restricted portion of the transmission line and thus to increase the velocity head to an amount that can be accurately read on a water column.

When thus used the pressure and velocity tubes are inserted permanently in a comparatively small pipe having a smooth inner surface as shown in Fig. 10. A considerable length of

this smooth restricted passage is provided in the approach to the measuring tubes, and fine screens are inserted ahead of them to prevent foreign substances from clogging the openings. The static head is indicated by a high-grade Bourbon gauge and the velocity head is observed in a water column. The scale is adjustable so that the zero can be set at the height of the water in the well to which the static pressure pipe leads. The observation of two water columns is thus avoided. Although the range in rate of flow of gas under any given pressure and temperature condition which can be accurately measured with one such Pitot tube unit, is less than one to three, the working range of a measuring station can be very effectively increased by putting several such units in parallel, as shown in Fig. 11.

FIG. 11.



Measuring station of parallel Pitot tube units.

Careful observations of pressure and velocity head are made at intervals sufficiently short to obtain correct averages. Very thorough and accurate calibrations have been made on these units from which have been established coefficients for each tube. By means of these coefficients and of tables for the reduction to a standard pressure and temperature each set of observations is reduced to standard cubic feet.

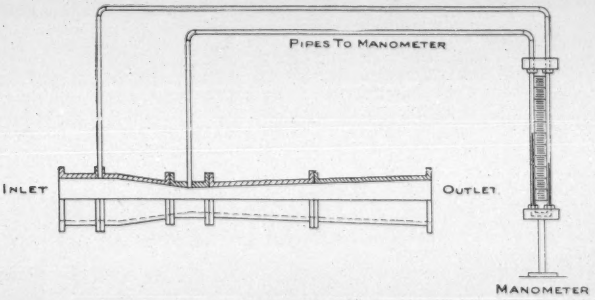
The Venturi meter, as shown in Fig. 12, has been used with some success in the practical measurement of gases. A paper by Mr. E. P. Coleman, published in the *Transactions of the American Society of Mechanical Engineers*, Volume 28, describes some interesting tests with such a meter.

Patient and consistent efforts have been made to develop devices which can be used in connection with Pitot or Venturi meters to give continuous graphical or integrated results. The fundamental difficulty in accomplishing this lies in the fact that

the power available for operating a recording or totalizing device is always very small, only that due to a few inches of water at the best. And even if the velocity head in a Pitot meter or the differential pressure in a Venturi throat could be satisfactorily recorded or integrated, attachments must be added to the device to correct the readings to a standard temperature and pressure if the temperature and pressure of the gas flowing through the meter are to vary more than a negligible amount.

It is noted that both these methods of measurement, when reduced to commercial form, involve a pressure drop in the gas through a restricted area. In the Venturi meter the increased velocity due to this drop is computed from the measured pres-

FIG. 12.



VENTURI METER.

sure drop which is assumed to take place adiabatically; while in the Pitot tube the velocity is increased to a value where it can be measured directly and accurately. They both measure the velocity of gas through a given area of passage and thereby measure the rate of flow in volumetric units. The electric meter differs from the other two in that it determines the quantity of gas by measuring the electrical energy required to maintain a constant small difference in temperature of the gas between its entrance to and its exit from the meter. The amount of heat necessary to increase the temperature of a given portion of gas depends on the mass, or amount of "stuff" in the given portion, and upon its specific heat. It does not depend upon the volume which the portion happens to occupy at the time of measure-

ment. The meter is therefore independent of the volume, or, in other words, of the pressure and temperature of the gas, so long as the specific heat remains constant. The experiments to be described are of particular interest in that they show that the specific heat of natural gas is constant within the very considerable range of pressures over which the tests extended. The same is true with regard to the tests on illuminating (artificial) gas, and on air, though with these the pressure range was not as great as it was in the natural gas experiments.

In its original form the electric meter was a means of supplying a known constant energy to the gas and of graphically recording the resultant rise in temperature. In its present commercial form it automatically maintains a constant temperature increase in the gas and measures the energy required to produce this increase. Temperature difference on the two sides of the heater can be maintained constant to a high degree of accuracy by a simple and reliable device in connection with resistance thermometers which regulates the electric energy in the heater. Since the specific heat of a unit weight of the gas remains constant for varying temperatures and pressures, and since the temperature rise is maintained constant, the weight of gas flowing must be directly proportional to the electrical energy dissipated in the heater. Thus with this meter the only quantity necessary to be measured is electrical energy, and this can be done accurately and reliably by means of well-developed commercial wattmeters of either the graphical or integrating type. Also, since the weight of gas is directly proportional to this electrical energy, the wattmeter dials may be made to read directly in standard cubic feet at any desired pressure and temperature.

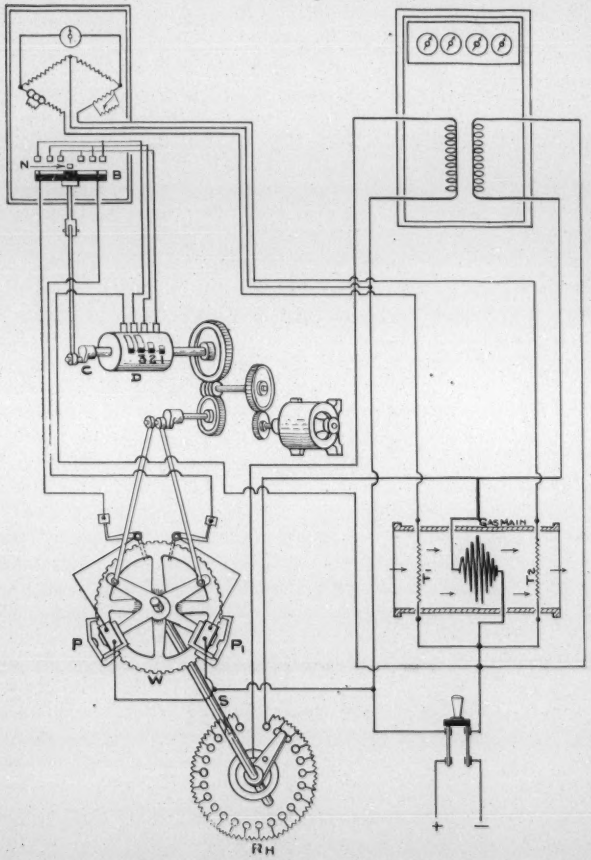
Thus the electric method lends itself easily and simply to a commercial design that gives continuous results in either a graphical or integrated form, directly in standard units, obtained without the necessity of calculation. The accuracy of the measurement is as great as that with which electrical energy can be measured.

THE COMMERCIAL ELECTRIC METER.

Fig. 13 is a diagrammatic sketch of the electric meter in the present commercial form. It differs from the manually controlled meter before described only in that it is provided with an auto-

matic device for maintaining a constant temperature difference in the gas on opposite sides of the heater unit. An increase

FIG. 13.

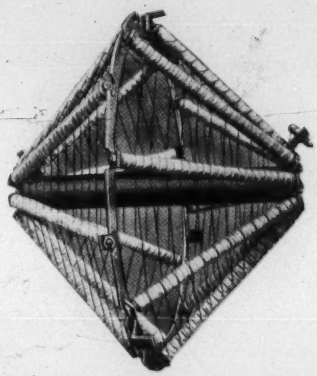


Diagrammatic sketch of automatic electric meter.

in rate of flow of gas through the meter will cause the thermometer T_2 to become less than its normal two degrees warmer

than thermometer T_1. This decreases the resistance of T_2 with respect to T_1 and causes a deflection of the galvanometer needle N to the right, the amount of the deflection depending upon the amount of change that has occurred in the rate of flow. On the shaft S of the rheostat R_h, which is in series with the heater, is a toothed wheel W. At the right and left edge of this toothed wheel two pawls, P and P_1, move with a continuous reciprocating motion through an arc having the length of three teeth on the edge of the wheel. A one-eighth horsepower motor

FIG. 14.

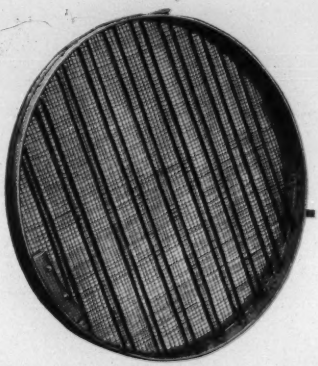


Heater unit for electric meter.

on the front of the panel runs continuously at constant speed and drives the bell cranks carrying these pawls. It also drives a contact drum D and a crank C, which causes a bar B to clamp the galvanometer needle N at intervals of a few seconds between a series of metallic contacts. If the change in gas flow has deflected the galvanometer needle so that it is clamped between the right-hand upper and the lower contact, the pawl P_1 will engage the toothed wheel when segment No. 3 on the revolving drum engages with its contact finger and energizes the magnet on P_1. This contact will occur when the pawl is at the bottom of its stroke, and the drum segment will keep the pawl engaged until it reaches the top of its stroke. Thus the deflection of the needle three divisions to the right has caused the

rheostat arm to be moved so that the heater energy has been increased three steps. Had the flow of gas decreased, the deflection of the needle would have been to the left and the heater energy would have been decreased. Had the deflection of the needle been only two divisions, the heater energy would have been changed two steps, etc. So long as the gas flow remains constant the galvanometer needle remains balanced and the heater energy remains unchanged. Thus the energy in the heater is automatically regulated to maintain a constant tem-

FIG. 15.

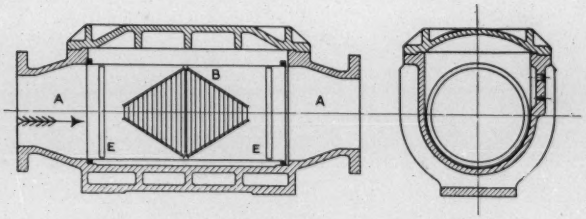


Resistance thermometer unit for electric meter.

perature difference of about two degrees F. in the gas. This accomplished, it only remains to measure the electrical energy in the heater, which is done by an integrating wattmeter, as shown in the diagram, or by a graphical wattmeter which traces on a record roll a continuous curve showing the rate of flow of gas at any time. Since the weight of gas flowing through the meter is always directly proportional to the watts dissipated in the heater, the wattmeters can be made to read directly in any standard weight units, such as pounds, or standard cubic feet of gas at atmospheric pressure and 60 degrees F., and they will always give results directly in these units, regardless of the actual pressure and temperature of the gas as it flows through the meter.

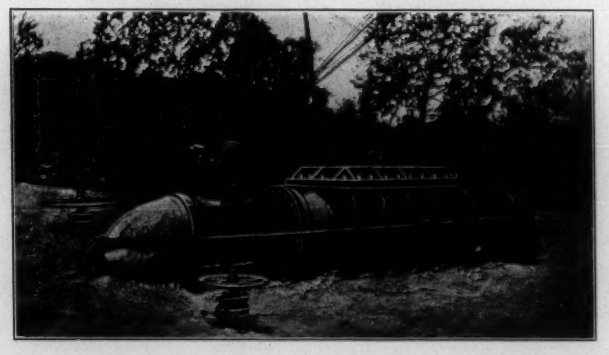
Fig. 14 is a photograph of a typical heater unit, in which the resistance wire is wound on a double-ended cone. Fig. 15 is a thermometer screen showing how the resistance material is distributed over the area of the pipe. Fig. 16 shows in section the heater and thermometer units assembled in the casing. In-

FIG. 16.



Sectional view of electric meter casing, showing heater and thermometer units in position.

FIG. 17.

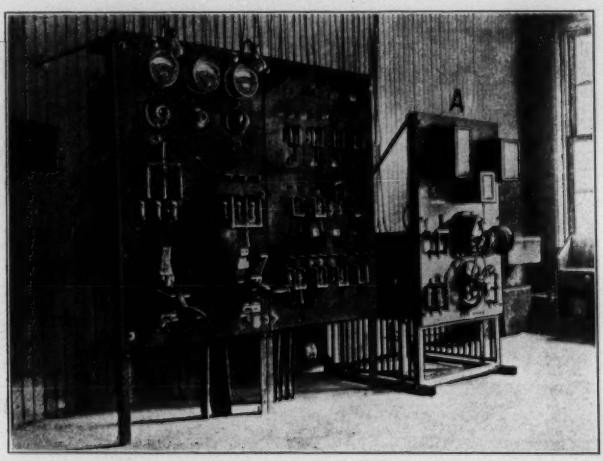


Electric meter installed in 10-inch suction pipe to natural gas pumping station.

side of the pressure casing is a light inner casing in which the units are assembled, and around which is a gas jacket to reduce loss of heat by radiation to a minimum. As the temperature of the gas is raised only 2 degrees F. this precaution is of little importance and has been dispensed with in some cases. However, the construction described is very convenient from an op-

erating standpoint, and incidentally provides the jacket space. The pressure casing is so designed that the cover can be removed and the inner casing with the units taken out for cleaning. Fig. 17 is a photograph of a meter casing in a field in a suction line to a natural gas pumping station. Electric wires lead from this casing to the recording panel, which is placed in any convenient location. Fig. 18 shows at *A* the recording panel having

FIG. 18.



Electric meter recording panel installed alongside of switchboards in lighting plant.

mounted on it the graphical and integrating wattmeter, the automatic control device, and the control switches.

CONDITIONS WHICH AFFECT SPECIFIC HEAT.

If a meter is to give satisfactory results for commercial uses the measurement must be based upon some property of the gas which, in the operation of the gas plant or pipe line, will not be so altered as to affect the results. Since with the electric meter the accuracy of the measurement depends entirely upon the specific heat of the gas, its accuracy will be affected only by

those conditions which change the specific heat of the standard unit of measurement.

That the specific heat of a standard cubic foot of gas is independent of the actual pressure and temperature of the gas within any ordinary working limits is not only in accordance with well-established theory, but it has been shown conclusively by tests that will be described later.

It is evident that a variation in composition of the gas will affect the specific heat somewhat. That this effect is in most cases entirely negligible is shown by the following comparisons.

Two typical analyses for artificial gases in a city plant are:

	Water Gas.	Coal Gas.
Co_2	3.8	2.2
CnH_2n	12.3	3.3
O	0.6	0.5
CO	30.4	6.9
H	33.3	50.6
CH_4	14.4	34.2
N	5.2	2.3

From these analyses are computed the values of specific heat of different mixtures of water gas and coal gas as given below. The values of specific heat are in B.T.U. per degree F. for a cubic foot of gas at 14.804 pounds absolute pressure and 60 degrees F.

Water Gas Per Cent.	Coal Gas Per Cent.	Specific Heat
100	0	.02094
90	10	.02096
80	20	.02098
70	30	.02100
60	40	.02102
50	50	.02104
40	60	.02106
30	70	.02108
20	80	.02110
10	90	.02112
0	100	.02114

The following table shows a typical variation in composition from day to day of mixed crude oil gas and carburetted water gas. To this table have been added the computed values of specific heat in B.T.U. per degree F. for a cubic foot of gas at 14.696 pounds absolute pressure and 60 degrees F.

Date June	CO_2	C_nH_{2n}	O_2	CO	H_2	CH_4	N_2	CP	BTU	Sp. Gr.	Sp. Ht
11	3.4	9.2	0.4	11.0	37.2	32.9	5.9	21.8	703	.518	.02168
12	3.5	9.7	0.4	9.8	36.6	33.2	6.8	22.9	710	.522	.02174
14	3.4	10.2	0.4	10.0	36.3	33.6	6.1	22.9	724	.523	.02182
15	4.0	10.0	0.4	10.6	35.8	32.5	6.7	21.4	708	.535	.02180
16	3.5	9.3	0.4	10.2	38.3	31.9	6.4	21.6	696	.512	.02167
17	3.4	9.6	0.2	10.0	36.7	34.6	5.5	20.9	724	.515	.02182
18	3.6	10.0	0.4	10.0	37.2	32.3	6.5	21.5	709	.521	.02173
19	4.0	9.6	0.2	10.6	34.5	34.0	7.1	22.1	712	.540	.02182
21	3.8	9.7	0.2	10.0	35.6	33.7	7.0	21.7	712	.531	.02182
22	3.7	9.7	0.4	10.2	37.2	32.9	5.9	22.0	710	.519	.02174
Avg.	3.63	9.70	0.34	10.24	36.54	33.16	6.39	21.88	710.7	.5236	.02176

Mean of ten values of specific heat computed from individual analyses ..... .02176

Maximum variation of specific heat computed for individual analyses from the specific heat computed for the average analysis ..... 0.4 per cent.

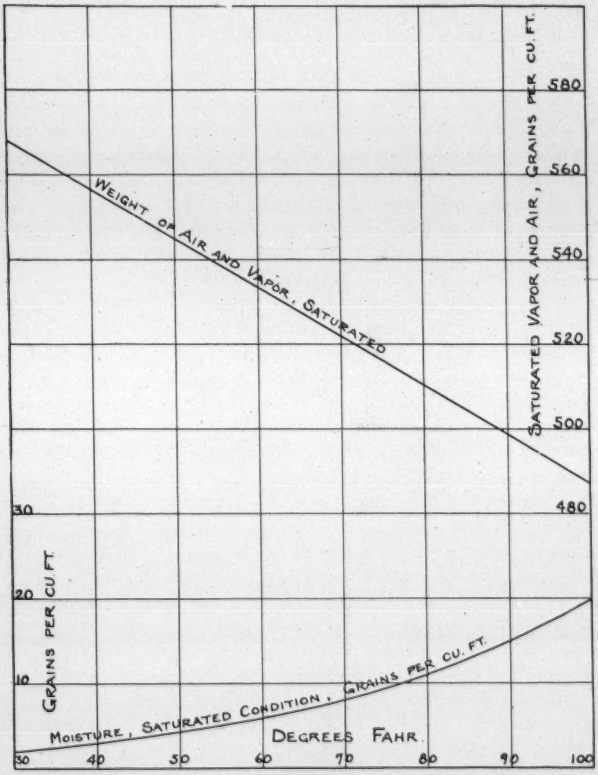
Two typical analyses of natural gas, with their corresponding computed specific heats are:

CH_4	79.95	88.74
C_2H_4	15.13	10.66
N	4.90	.22
O	.02	.16
CO_2	.....	.22
Specific heat per cu. ft. at 60° F., and 15.025 lbs. absolute pressure	.02599	.02609

A certain amount of water vapor forms a part of almost all gases, including atmospheric air. The curves in Fig. 19 show the weight of water vapor in air at different temperatures and at 100 per cent. humidity. This can be expressed as a percentage of the total weight of air and vapor. Thus at 60 degrees F., 30-inch barometric pressure, and 100 per cent. humidity, the weight of a cubic foot of air and vapor is 533 grains, and from the lower curve it is seen that it is possible under saturated conditions for the cubic foot of space to hold 5.6 grains of water vapor. The water might then amount to 1.05 per cent. of the weight of the air, and as the specific heat of water vapor is approximately twice that of air, the correction due to fully-saturated water vapor would amount to about one per cent. This

correction can be made by the use of curves similar to those shown, on the basis of an assumed or an ascertained humidity.

FIG. 19.



Curves showing weight of water vapor in air at different temperatures and at 100 per cent. humidity. Note that the two curves are drawn to different scales.

This is rarely 100 per cent., the normal relative humidity being more nearly 50 per cent., and the correction, therefore, about

one-half of one per cent. If the gas is over-saturated, and the water is carried in it mechanically as a fog or mist, the evaporation of this by the meter itself, of course, interferes with making accurate measurements. In such cases it is necessary to transform the fog or mist into dry vapor by the introduction of heat to the gas before it enters the meter.

SOME PRACTICAL REQUIREMENTS OF CONTINUOUS RUNNING METERS.

Whenever the measurement of gas plays an important part in the operation of a plant it is necessary to know that the meters are measuring accurately, and they are inspected at regular intervals and checked whenever possible. With the electric meter it is possible to check the condition of the parts inside the gas main from the recording panel without opening up the meter. If the heater circuit is broken and the temperature difference resistance is shorted out while gas is flowing through the meter, the two thermometer units will come to equal temperatures and the galvanometer needle will come to a balance in its central position. Should anything have happened to change the thermometers, which are the basis of measurement, the trouble is thus easily detected. A small rheostat is provided in series with one thermometer to bring them back to a balance if they should be slightly unbalanced.

Deposits on the inner parts of a meter are always liable to occur to some extent, and these must not affect the accuracy of measurement. Such deposits on the heater unit in the electric meter cannot affect the accuracy, since the heater is only a means of dissipating energy and this energy is measured by wattmeters independently of the resistance or surface of the heater unit. Moderate deposits on any of the inner parts of the meter will tend to make the units somewhat slower in their response to changes in flow, but will not affect the accuracy of measurement. The heat is all dissipated within the meter casing and must necessarily all go into the gas.

A meter designed for continuous service under ordinary operating conditions must have as large a range as possible between maximum and minimum rates of flow at which it will measure accurately. The electric meter has in general a range of about 15 to 1 in capacity. If it is desired to measure low

rates of flow accurately with a high capacity meter, two temperature difference resistances are provided instead of one. By shifting a resistance plug and dividing the wattmeter readings by the ratio of the two temperature differences, the possible accurate range of a single unit can be increased to about 60 to 1.

If a meter is to run continuously the cost of operation must not be excessive. With the electric meter about one kilowatt-hour of energy is required to measure 75,000 cubic feet of free gas. Assuming that one kilowatt-hour can be obtained from 50 cubic feet of gas, the cost of operation of the meter is equivalent to less than one-tenth of one per cent. of the gas that it will measure. As this percentage is well within the limit of the possible accuracy of measurement, the cost of operation is seen to be very moderate. Since the results are graphically recorded or integrated, no observations need to be made and the labor cost for care is reduced to a minimum.

COMPARATIVE TESTS OF COMMERCIAL METERS.

I. *With Artificial Gas and Air.*

Some very interesting tests have been made to check the accuracy of the electric meter against the wet displacement meter as a standard in low-pressure artificial gas work, and against the Pitot tube as a standard in high-pressure natural gas measurement.

During the development stages tests were made with the electric meter in series with a wet displacement meter with both air and illuminating gas in the Third Ward Plant of the Milwaukee Gas Light Company. This meter was of the constant energy, variable temperature type. Fig. 20 is a portion of a graphical record of the test showing rates of flow varying from 17,000 to 75,000 cubic feet per hour. The energy input during this test was approximately 1.15 kilowatts.

Let G = cubic feet of gas flowing per hour.
E = energy supplied in kilowatts.
T = temperature difference in degrees F.
S = specific heat per cubic foot.

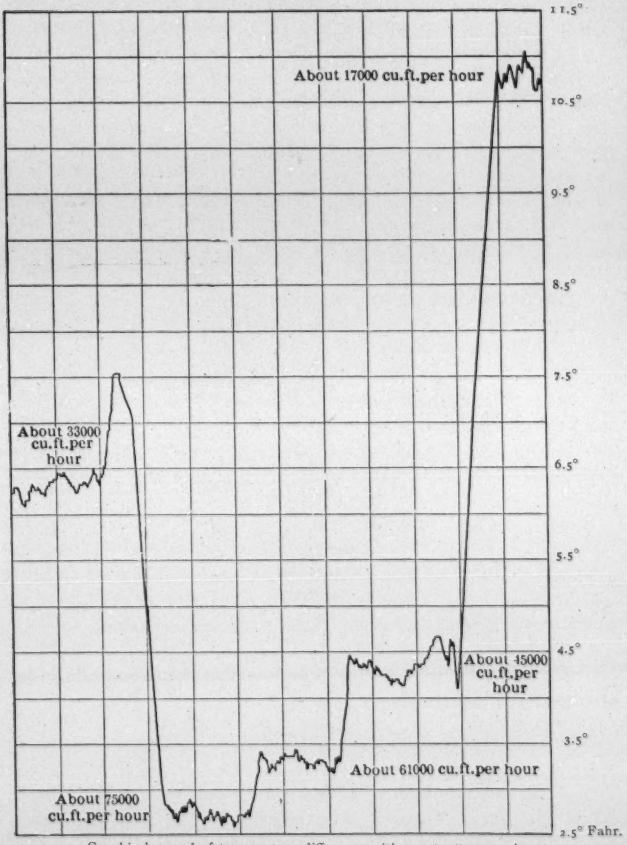
Then

$$GST = 3412\,E \text{ and } G \times \frac{T}{E} = \frac{3412}{S} = \text{a constant.}$$

If, then, values of G, or the cubic feet of gas per hour obtained

from the wet meter, are plotted as ordinates, and values of $\frac{T}{E}$, or the temperature rise per kilowatt input to the electric

FIG. 20.



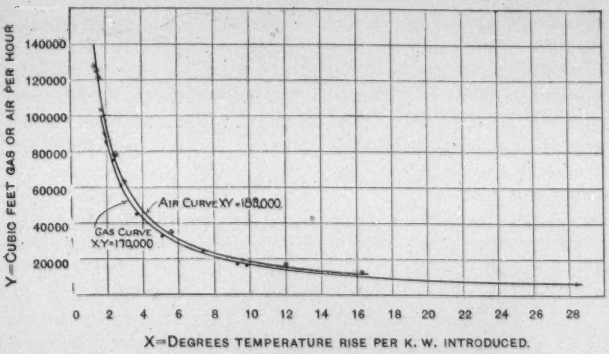
Graphical record of temperature difference with constant energy input.

meter, be plotted as abscissæ, the resultant curves should be rectangular hyperbolas. That they are asymptotic to the co-

ordinate axes is apparent because, when an infinitely great amount of gas is being heated, any finite input of heat will produce only an infinitely small rise of temperature, and, on the other hand, when the amount of gas becomes infinitely small, a finite input of heat will cause an infinitely great rise in temperature.

It is obvious from the curves shown in Fig. 21 which were plotted from the experimentally determined points for both the gas and air tests, and which are true hyperbolas, that the results obtained are in complete accord with well-established theory.

FIG. 21.



Rectangular hyperbolas plotted from gas and air tests.

For the gas curve it is found that the constant $\frac{GT}{E} = 170{,}000$, while the corresponding constant for air $= 188{,}000$. Since $\frac{GT}{E} = \frac{3412}{S}$, it follows that the specific heat of the gas during the test was $\frac{3412}{170000}$, or 0.0201 B.T.U. per cubic foot, and that the specific heat of the air was $\frac{3412}{188000}$, or 0.0181.

The conditions during the gas test were as follows: Barometer 29.8 inches, gas pressure 6 inches water, average temperature of gas measured in the wet meter 59 degrees F. If the specific heat thus obtained is reduced to standard conditions of 32 degrees F. and 29.9 inches mercury, then $S = 0.0210$,

which is to be compared with the calculated value for specific heat of 0.0211 from the analysis of the gas given below.

	Volume cubic feet	Weight per cu. ft., lb.	Total weight lb.	Specific heat per lb.	Specific heat per cubic ft.
CO_2	0.04	0.11637	0.004658	0.216	0.00100
C_2H_4	0.11	0.0741	0.00815	0.404	0.00329
O_2	0.001	0.08463	0.00085	0.217	0.00023
CO	0.331	0.07407	0.02450	0.245	0.00600
CH_4	0.1761	0.04324	0.00746	0.593	0.00442
H_2	0.303	0.00530	0.00160	3.409	0.00546
N_2	0.0389	0.07429	0.00289	0.244	0.00071
					0.02111

During the air tests the conditions were as follows: Barometer 29.75 inches, air pressure 6.5 inches water, average temperature of air measured in wet meter 60 degrees F. Reducing the value for specific heat obtained by the test under these conditions to standard conditions of 32 degrees and 29.9 inches mercury, $S = 0.0191$. This is to be compared with the accepted specific heat of air under these conditions, or 0.0192 B.T.U. per cubic foot. Since the specific heat of air is well known and since the wet meter is a very accurate device at the conditions under which the measurements were made, these tests provide the very best evidence of accuracy of the electric method of measurement. The wet meter was put in first-class condition and thoroughly tested and regulated before the tests were made.

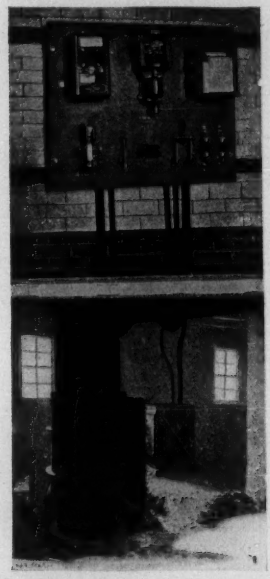
Fig. 22 shows an installation of the electric meter in the West Side Plant of the Milwaukee Gas Light Company designed to measure continuously and to give both graphical and integrated records of the total supply of artificial gas to the city of Milwaukee. The meter casing replaced a short vertical section of 30-inch pipe line in the basement of the pumping station leading from the pumps to the distributing lines of the city, while the recording panel, having mounted on it the recording instruments and control switches, is located on the wall where it can be conveniently operated and read from the pumping station floor. This meter has a maximum capacity of 3,000,000 cubic feet of free gas per hour and an accurate minimum capacity of 50,000 cubic feet. Fig. 23 is a portion of a graphical record made by this meter showing the peak in total output caused by the cooking load at noon. The steps in the sides of this peak

show the sudden changes in rate of flow caused by the operation of the control valve in the pump discharge.

II. *Tests With Natural Gas.*

At the Brave Pumping Station of the People's Natural Gas Company of Pittsburgh is installed an electric meter for the

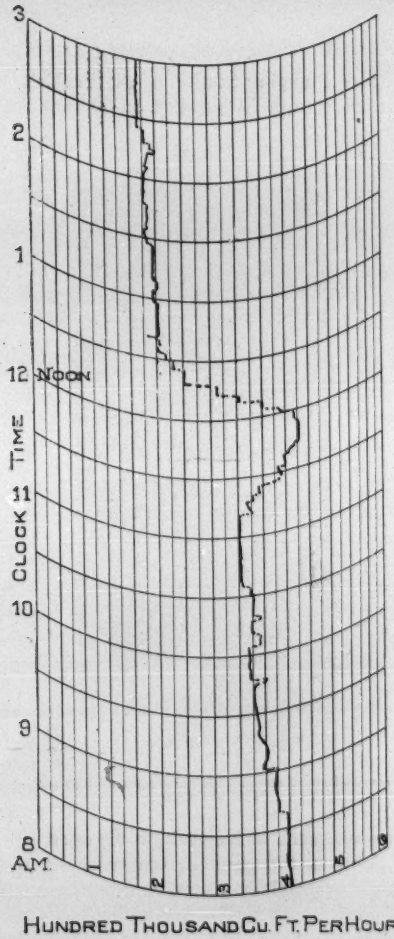
FIG. 22.



Electric meter installed in basement of pumping station, with recording panel on main floor above.

continuous measurement of natural gas between the wells and the pumps. This meter gives in the office of the pumping station a continuous graphical record as well as integrated values of the flow of gas through the line in which it is installed, directly in standard cubic feet, at 15.025 pounds absolute pressure and

FIG. 23.



Graphical record from electric meter showing a peak load in a city's gas supply.

60 degrees F., although the pressure of the gas varies from 50 to 200 pounds gauge, and the temperature varies with weather conditions.

The meter casing is installed in a field just above the level of the ground, immediately between two elbows and close to gate valves, and is in a 10-inch suction line within about 200 feet of the suction header of the pumping station, as shown in Fig. 17. The recording panel is installed, as shown in Fig. 18, alongside of the switchboards in the lighting plant from which the meter receives its supply of energy. The meter has a maximum capacity of 750,000 cubic feet of free gas per hour and an accurate minimum capacity of 12,500 cubic feet. It was designed to give readings directly in standard units, the specific heat of which was computed from an analysis assumed from an average and to correspond to the standard pressure and temperature stated above. This installation has afforded an unusual opportunity for checking the accuracy of the meter on account of the very wide variations in pressure and rate of flow of the gas through the line in the ordinary operation of the system, and also because there is installed at Bula a very complete and thoroughly calibrated Pitot tube station, similar to that shown in Fig. 11, one tube of which is in the same line with the electric meter. The two meters can thus be run in series, although they are separated by about one and one-half miles of 10-inch pipe. Readings of pressure and velocity head are taken on the Pitot tube every fifteen minutes, day and night, and from these readings values of gas flow in standard cubic feet are obtained by the use of carefully prepared tables. As these tables reduce the Pitot tube readings to the same standard units in which the electric meter was designed to read, the results are directly comparable.

Very thorough tests were made on the electric meter under service conditions to determine the degree of accuracy with which it would give continuous results directly in standard cubic feet with variable pressures, temperatures, and rates of flow as compared with the results obtained by very frequent and careful observations on the Pitot tubes, and also to learn whether all the parts would stand up satisfactorily against wear and the action of the gas.

The following table shows the hourly results of a comparative test of 22 hours' duration. During a large part of this test the rate of flow was kept nearly constant and the temperature of the gas remained about the same, but the pressure varied from 72 to 123 pounds gauge. The values of cubic feet for each hour are obtained from the chart by averaging the curve traced by the meter; from the integrating meter by subtracting the dial reading at the beginning of the hour from that at the end; and from the Pitot tube in the manner described above.

Hour	Cubic feet each hour			Total cubic feet at end of each hour		
	Chart	Integrating meter	Pitot tube	Chart	Integrating meter	Pitot tube
8– 9	397500	400000	400297	397500	400000	400297
9–10	398500	398000	394027	796000	798000	794324
10–11	370000	374000	373731	1166000	1172000	1168055
11–12	376500	377000	380800	1542500	1549000	1548855
12– 1	361500	364000	367726	1904000	1913000	1916581
1– 2	370900	377000	377694	2274900	2290000	2294275
2– 3	381200	387500	386103	2656100	2677500	2680378
3– 4	380900	386500	387815	3037000	3064000	3068190
4– 5	382600	384000	387229	3419600	3448000	3455419
5– 6	385510	388000	389052	3805110	3836000	3844471
6– 7	391250	388000	392161	4196360	4224000	4236632
7– 8	395000	391000	394654	4591360	4615000	4631286
8– 9	394500	392000	392416	4985860	5007000	5023702
9–10	397500	398000	392245	5383360	5405000	5415947
10–11	387000	383000	385383	5770360	5788000	5801330
11–12	388000	387000	387104	6158360	6175000	6188434
12– 1	378000	373000	386983	6536360	6548000	6575417
1– 2	439500	436000	435416	6975860	6984000	7010833
2– 3	447000	446000	445945	7422860	7430000	7456778
3– 4	463000	459000	465896	7885860	7889000	7922674
4– 5	465000	464000	467240	8350860	8353000	8389914
5– 6	407500	411000	394886	8758360	8764000	8784800

After this run a 45-day test was made on the two meters under service conditions, during which time but very few interruptions occurred in the gas flow. Readings were taken on the Pitot tube as before, and results were obtained from the electric meter by means of the continuous records and by reading the integrating instrument at intervals of three hours. The following is a sample log sheet for a 24-hour period of the test:

NOON APRIL 26th TO NOON APRIL 27th, 1911.

Time	Integrating meter reading	Cubic feet integrating meter	Cubic feet chart	Cubic feet Pitot tube	Pressure		Temp.	
					Brave	Bula	Brave	Bula
12:00	2498.0							
3:00	2603.6	1056000	1030800	1056539	134	140	47	46
6:00	2714.3	1107000	1073400	1115176	157	161	47	43
9:00	2831.7	1174000	1134000	1160802	156	160	47	43
12:00	2965.0	1333000	1321200	1311671	162	167	47	43
3:00	3086.7	1217000	1230600	1226774	162	166	47	42
6:00	3215.0	1283000	1302900	1310577	114	124	47	40
9:00	3375.0	1600000	1631400	1614811	113	125	47	40
12:00	3523.2	1482000	1479000	1480000	135	143	47	46
Totals		10252000	10203300	10276350				

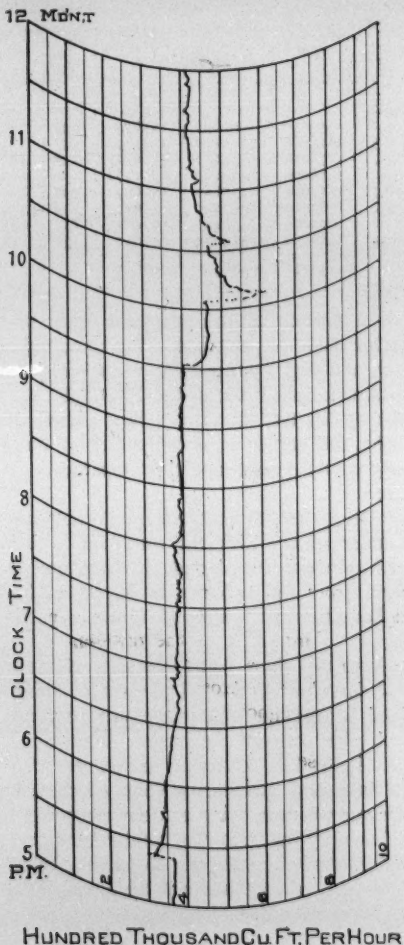
Fig. 24 is a portion of the graphical chart made by the electric meter for the same period, showing some sudden changes in rate of flow, and Fig. 25 shows the variations in pressure as plotted from observations made at the Pitot tube.

During the 45-day test the rate of flow varied from 90,000 to 640,000 cubic feet per hour, the pressure of the gas varied from 46 to 185 pounds gauge, and the temperature varied from 45 to 65 degrees F.

In order to study the comparative results obtained from the two meters under all the different conditions existing during the test a graphical chart was plotted, showing total comparative results obtained from the two meters during each three-hour period throughout the test. Fig. 26 shows a portion of this chart.

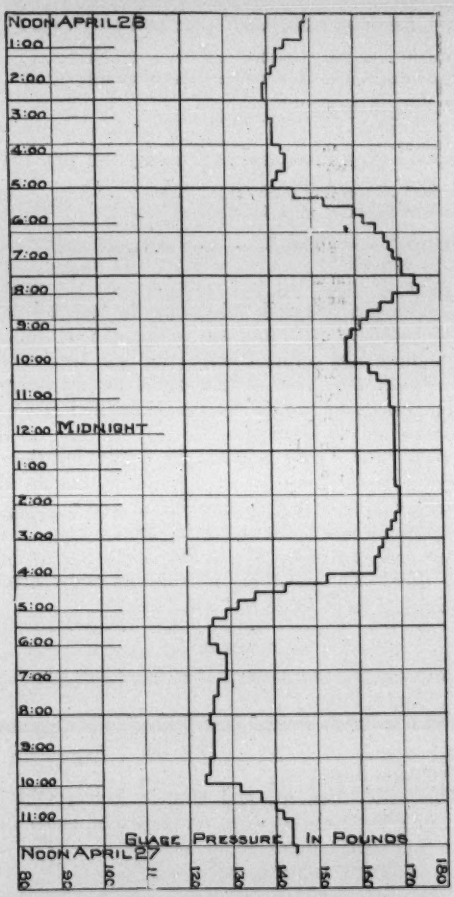
It is seen from this chart that the results of the two meters varied slightly for short periods, but most of these cases are easily explained by the fact that there were several thousand feet of 10-inch pipe between the meters, that the flow of gas was controlled by sudden changes, sometimes at Brave and sometimes at Bula, and that during some of these periods the pressure of the gas was increasing or decreasing over quite wide ranges. As shown by the following total results for the whole test, these slight errors averaged out in longer periods of time, and the two methods of measurement gave practically identical results in both the short and the long tests.

FIG. 24.



Graphical record from electric meter showing sudden changes in rate of flow.

FIG. 25.



Graphical log of gas pressures for a 24-hour period of the test at Brave, Pa.

The following is a summary of the results of the tests:

22-HOUR TEST, APRIL 9TH AND 10TH, 1911

Total standard cubic feet of gas for 22 hours by Pitot tube....	8,784,800
Total standard cubic feet of gas for 22 hours by electric meter	8,764,000

$$\frac{8,784,800 - 8,764,000}{8,784,800} = 0.2\% \text{ difference.}$$

ENDURANCE TEST, APRIL 17TH TO JUNE 3RD, 1911

Total standard cubic feet of gas by Pitot tube.....	337 546,182
Total standard cubic feet of gas by electric meter.....	336,732,018

$$\frac{337,546,182 - 336,732,018}{337,546,182} = 0.2\% \text{ difference.}$$

In order to make the test complete and the results more conclusive, the gas was analyzed during the test and the specific heat of the standard cubic foot was computed from this analysis. Although the actual composition of the gas was found to be considerably different from that assumed for the design of the meter, the values of specific heat as computed from the two analyses were almost identical.

After the tests were completed the heater and thermometer units were removed from the casing and thoroughly inspected. They were found to be in perfect condition, and the only deposits to be found anywhere inside the casing were a very thin coating of fine dark-brown powder, almost dry, and a few finely divided pieces of scale. The recording instruments and control device were also found to be in perfect condition.

SUMMARY.

The discussions and tests in the preceding pages may be summarized as follows:

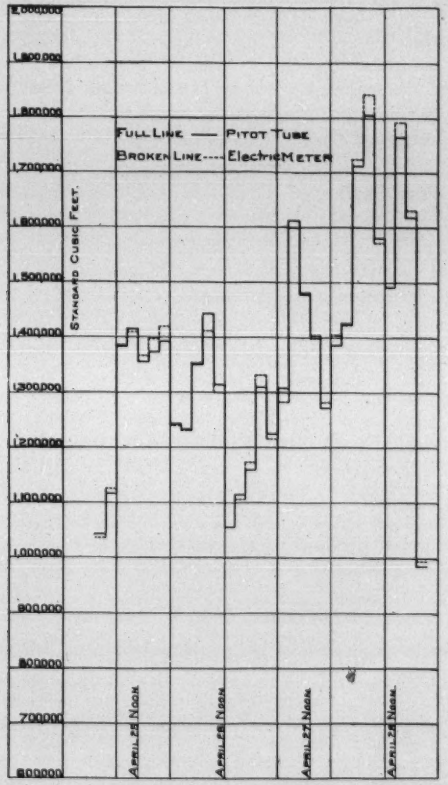
I. Formulæ for theoretical flow through pipes are useful for the design of pipe lines, but not for the measurement of flow through existing lines.

II. The Pitot, Venturi, and electric meters will all give accurate and reliable results when properly used under favorable conditions and when observations are taken with a sufficient degree of refinement in methods.

III. The electric meter will give continuous results, either graphical or integrated, even under severe commercial conditions of operation, that compare most favorably with the best that can

be obtained with other forms of direct reading meters or by frequent observations on Pitot tubes and the use of tables and

FIG. 26.



Portion of graphical chart showing comparative total results for each three-hour period for four days of 45-day test at Brave, Pa.

coefficients derived from the most thorough calibrations; and it will give these results directly in any standard units desired, re-

gardless of the pressure and temperature of the gas flowing through the meter.

From a scientific standpoint it is interesting to note the remarkably close agreement of results that have been obtained in the tests by the several methods, which differ fundamentally in principle. The tests with natural gas at varying pressures also furnish an interesting check upon the generally-accepted statement that the specific heat of gases at constant pressure remains practically constant throughout the range of pressures commonly found in engineering.

The Rare Earths. C. R. BÖHM. (*Z. Angew. Chemie*, xxiv, 1203.)—Zirconia, which is now more easily obtained from the native Brazilian zirconia than from zircon, is utilized in pottery, enamels, arc lighting, and in Röntgen ray therapeutics, and probably has a great future. For incandescent gas-lighting it cannot displace thoria, as thorium nitrate gives a more coherent and resistant product. This is probably due to its power of forming a foam-like mass on heating, which can be increased by adding about 2 per cent. of sulphuric acid before evaporating the solution. The formation of a voluminous and finely divided ash serves as a ready technical test of the quality. Thorium nitrate is specially suitable for mantles made of cotton and ramie fibres; but it swells too readily for use with artificial silk; in this case ammonia or other alkali is added to the impregnating liquid, or the impregnated material is treated with hydrogen peroxide. Ceria is the most easily procured rare earth; it constitutes about 50 per cent. of the waste product from the thorium industry. It can be used for incandescent lighting. Prior to the introduction of the metallic filament lamps, considerable quantities of yttria from gadolinite and of zirconia from zircon were used in the manufacture of Nernst lamps.

Photographic Irradiation. C. E. K. MEES. (*Astrophys. Jour.*, xxxiii, p. 81.)—The diameter of the photographic image of a star or spectral line is known not to be the real diameter of the object, and as different systems for the measurement of these quantities have been used as criteria for photographic photometry, it becomes necessary to investigate their relation to each other. Hitherto the general conclusion has been that the square root of the diameter of a star image is proportional to the logarithm of the exposures. Laboratory experiments were made with an illuminated slit photographed from a distance of 3 metres by a lens of 15 cm. focus, so that the reduction on the plate was approximately 20:1. The slit was illuminated by a Nernst burner, and the diameter of the developed images read with an eye-piece micrometer, one division being equal to 0.0075 mm. The results confirmed the law usually accepted.

THE EXAMINATION AND PHYSIOLOGICAL ACTION OF PATHOGENIC MINE ATMOSPHERES, WITH CONSIDERATIONS GOVERNING THE USE OF BREATHING APPARATUS.

BY

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THE atmosphere of a mine, and its relation to those workers whose lives it must support, is a subject of engrossing interest. While much space has been devoted, in the past, to the general topic of ventilation, it is but recently that a closer view has been taken of the subject, and a more minute discussion of the various integral constituents of the mine atmosphere has been entered into. A reason for this change is not far to seek. The past decade has witnessed the introduction of so-called "rescue" or "breathing" apparatus. As the aim of all such apparatus is to permit the wearer to penetrate an atmosphere which, for some reason, is incapable of supporting life, it is only natural that a careful investigation should have been made into the changes which take place in a normal atmosphere, causing it to become toxic or irrespirable. As any device designed to support life, under these abnormal conditions, must supply the wearer with an atmosphere more or less independent of the exterior, it follows that a study of the amount of air required by the average man under various conditions of physical work should have become all-important.

In the course of this paper the writer will attempt to discuss only those atmospheres which are likely to be met with in mines. From time to time terms applied by mining men to various atmospheres or constituents of an atmosphere may be used.

It might, therefore, be well to define at once what these terms are intended to convey. "Black" or "choke damp"[1] is the residual gas left after the partial or complete removal of the oxygen

[1] Investigations on the Composition, Occurrence, and Properties of Black Damp, Haldane and Atkinson, *Trans. Inst. Min. Eng.*, vol. 8, p. 549.

from the air. It is seldom found in a pure state, generally being mixed with proportions of normal air. In the pure state it may

TABLE I.

COMPOSITION OF BLACK DAMP.

	O	N	CO_2	CH_4	Air	Black damp	Fire damp
1. Podmore Hall Coll'y stopping in No. 4 Pit.....	1.45	82.56	10.64	5.35	6.94	87.71	5.35
2. Same, two months later.....	0.72	80.78	11.03	7.47	3.44	89.09	7.47
3.	10.09	89.38	0.05	0.48	48.23	51.29	0.48
4.	5.08	91.81	2.92	0.19	24.30	75.51	0.19
5.	0.90	93.01	3.05	3.04	4.33	92.63	3.04
6.	trace	94.79	2.68	2.53	trace	97.47	2.53

Analyses 1 and 2 were taken from "Black Damp," by Haldane and Atkinson, *Trans. Inst. Min. Eng.*, vol. 8, p. 551.

Analyses 3, 4, 5, and 6 are from the author's experience and are representative of black damp from anthracite mines.

TABLE II.

COMPOSITION OF FIRE DAMP.

	O	C_nH_{2n}	N	CO_2	CH_4	Air	Black damp	Fire damp
1. Fire damp from pipe inserted in coal, Minnie Pit, Podmore Hall....	0.1		9.4	4.1	86.4	0.5	13.1	86.4
2. Garswood Hall.			2.24	.86	84.16	12.64		84.16
3. Garswood Hall.			2.27	.86	88.86	8.01		88.86
4. Accumulation of gas at roof.		0.09		1.45	50.67	29.33	19.91	50.67

Analysis 1 is taken from "Black Damp," Haldane and Atkinson, *Trans. Inst. Min. Eng.*, vol. 8, p. 554.

Analyses 2 and 3 are taken from "Elementary Chemistry for Coal Mining Students," O'Shea, p. 119.

Analysis 4 is taken from *Bull. 383, U. S. Geol. Sur.*, p. 31.

be roughly said to consist of from 85 per cent. to 99 per cent. of nitrogen, and from 1 per cent. to 15 per cent. of carbon dioxide. "White damp" is the name given by miners to carbon

monoxide. "After damp"[2] is a mixture of air, black damp, white damp, and carbon dioxide. It results from the explosion of mixtures of fire damp or coal dust and air, and when fresh is sometimes deeply colored by smoke or soot. A gas of similar composition results from underground fires. "Fire damp"[3 4] is a combustible gas composed principally of methane, but also containing small proportions of hydrogen, ethane and higher hydrocarbons. It always occurs mixed with varying amounts of oxygen, nitrogen, and carbon dioxide. Analyses are given in Tables I and II of airs containing these bodies.

The first step in a systematic study of mine atmospheres should be the collection of reliable analytical data. It is important to know exactly the proportion of oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrocarbon gases calculated as methane, and, in rare instances, hydrogen sulphide and sulphur dioxide.

The practical value of such information is hardly as yet appreciated by mine operators in general. It might, therefore, be well to mention, in passing, a few applications of these data.

By a careful study of well-chosen analyses of air from different entries and returns, throughout a mine, it is possible to discover regions receiving ventilation in excess of their needs. When this excess air is diverted to regions more in need of ventilation an insufficient air supply may sometimes be made adequate.

When an attempt is being made to extinguish a mine fire by cutting off its air supply, it is possible by the analysis of samples taken through bore holes or pipes in stoppings to obtain very accurate information as to the progress of the work. It is also possible, by this means, to detect at once any access of fresh air.

When an atmosphere of questionable purity is to be entered, for the purpose of doing rescue work or fighting mine fires, the advantage of applying tests for its respirability is self-evident.

Thus a party equipped with breathing apparatus might precede their unprotected companions and accurately ascertain just how far it was safe for the latter to proceed. While men were at

[2 3] Notes on Explosive Mine Gases and Dusts, Chamberlin, *U. S. Geol. Survey, Bull.* 383.

[4] Fire Damp: Its Composition, Detection, and Estimation, Gray, *Trans. Inst. Min. Eng.*, vol. 39, p. 286.

work without breathing apparatus; in a dangerous environment, one of their number could, by making frequent tests, determine any increasing toxicity of the air and thus warn his companions in time for a safe retreat.

Under certain conditions the so-called "safety lamp" ceases to yield reliable indications, and more precise methods must be looked to. For example, in testing a body of black damp, containing below 16 per cent. of oxygen and 6 per cent. to 7 per cent. of methane, the lamp will first show a pronounced cap. As the lamp is approached more closely to this body of gas, the cap will increase in size, and may eventually entirely fill the gauze. On entering the body of damp, however, the flame will be extinguished. As this behavior is supposedly characteristic of a body of pure fire damp, the most experienced miner may be led to a false diagnosis, the true nature of the gas body only being discoverable by chemical analysis.

The actual analysis of a sample of mine air is by no means as simple a matter as might at first appear. To begin with, the limit of error permissible in such work is of an entirely different order from that in the analysis of fuel or flue gases. The constituents to be determined, with the exception of oxygen and nitrogen, are for the most part present in extremely small quantities, while the presence or absence of one or two of these may be of vital importance. Thus the classic methods based on the selective absorption in rotation of the various components of a gaseous mixture, the quantity of each being estimated by the decrease in volume of the gas, are unsatisfactory, except in the determination of oxygen. By this procedure such a small volume of sample is operated upon, and the substances to be determined are present in such small quantities, that the error is unpermissibly great. It is true that Haldane[5] has devised a very ingenious apparatus working on the above principle. It has been the author's experience, however, that the apparatus is so complicated and its manipulation so cumbersome that other methods are preferable.

With these points in view, the writer has, after considerable experimentation, selected a number of methods from the literature, and has found them to give most satisfactory results. A

[5] The Investigation of Mine Air, Foster and Haldane, p. 97.

detailed description of these methods would lie without the scope of this paper. It will suffice, therefore, briefly to touch upon their salient points.

The gas samples are collected in copper cylinders of about 3 litres capacity, with conical ends, each end carrying an accurately ground tubulated brass stop cock. When a sample is to be taken, a cylinder is filled with clear water, and carried to the desired spot. On opening the cocks, the can will be filled with air as the water recedes. As soon as the can is free of water the cocks should be closed. If the sample is to be taken from a pipe or bore hole, a rubber tube of small bore, previously filled with water, is slipped over one of the cocks. The tube may then be thrust or lowered into the pipe or bore hole to the desired point. While holding the cylinder in a vertical position, with the cock bearing the rubber tube uppermost, the cocks are opened, when the desired sample will be drawn into the cylinder. It is important in using these cans to allow all water to drain out, when taking the sample, and to make the analysis as soon as practicable.

Carbon dioxide is determined by the method of Pettenkofer [6] or Hesse. This method has many variations. The following, however, has been found to give thorough satisfaction: A heavy litre or litre-and-a-half Erlenmeyer flask, the volume of which has been previously determined, is filled with water at room temperature, and then filled, by displacement, with the air to be analyzed. The flask is closed with a well-fitting two-hole rubber stopper, the apertures of which are closed by glass rods. A known excess of a clear solution containing 15 gm. of barium hydroxide and 1 gm. of barium chloride per litre is then run

[6] A Systematic Handbook of Volumetric Analysis, Sutton, 10th ed., p. 102.
Methods of Gas Analysis, Hempel, 3d German ed., p. 346.
Handbook of Technical Gas Analysis, Winkler and Lunge, 2d English ed., p. 103.
The Investigation of Mine Air, Foster and Haldane, p. 44.
Quantitative Chemical Analysis, Olsen, 4th ed., p. 301.
Quantitative Chemical Analysis, Clowes and Coleman, 8th ed., p. 476.
A System of Instruction in Quantitative Chemical Analysis, Fresenius, 2d American ed., p. 776.
Analytical Chemistry, Treadwell, vol. 2, 2d ed., p. 551.
Technical Methods of Chemical Analysis, Lunge, p. 870.

from an automatic pipette through one of the holes of the stopper. After closing, the flask is allowed to stand, with frequent shaking, for at least a half hour. At the end of this period the rods are withdrawn, the barium hydrate solution is tinted with phenolphthalein, and cautiously titrated with gas-normal oxalic acid. This solution contains 5.629 gm. of crystallized oxalic acid per litre, 1 c.c. being equivalent to 1 c.c. of carbon dioxide, measured at 0° C. and 760 mm. pressure. While the carbon dioxide is being absorbed, another portion of the barium hydroxide solution is titrated with the oxalic acid. From this determination the ratio of oxalic acid to barium hydroxide is found. The volume of carbon dioxide in the sample operated upon is thus readily obtained by subtracting from the volume of oxalic acid, equivalent to the quantity of barium hydroxide originally taken, the volume of oxalic acid required after the absorption of the carbon dioxide. In calculating the percentage of carbon dioxide, note must be made of the thermometer and barometer readings when the flask is filled with air for analysis. From these values the volume of the air contained is reduced to normal conditions, first deducting the volume of the barium hydroxide added. Great care should be taken in adding the barium hydroxide, as well as in the subsequent titration, that there be as little opportunity as possible for the air in the flask to mix with the outside air. Most commercial samples of barium hydroxide contain some alkali metal hydroxide. In such a case alkali metal oxalate may be formed, when at the close of the titration the following reaction will occur:

$$Na_2C_2O_4 + BaCO_3 = BaC_2O_4 + Na_2CO_3$$[1]

Under these conditions the bleaching of the color of the phenolphthalein is not permanent, the color returning after repeated addition of acid, and thus shrouding the end point in uncertainty. By the addition of barium chloride the alkali metal hydroxide is converted to chloride and rendered innocuous, the end point once more becoming sharp. As the dilute solution of oxalic acid used is far from stable, a fresh solution should be frequently prepared. The barium hydroxide solution should be protected from the carbon dioxide of the air by the usual methods. The accuracy of this method has been demonstrated by the exhaustive

[1] Quantitative Chemical Analysis, Olsen, 4th ed., p. 303.

researches of Letts and Blake.[8] Its precision will become apparent when it is considered that, granting the burette may be read to 0.05 c.c. and that 1000 c.c. of air are operated upon, the error in reading should not exceed 0.005 per cent. of carbon dioxide. There is, of course, an ever-present error due to the solution of carbon dioxide in the water when filling the sample can and transferring the air to the flask. This error, however, is small with careful work. Hydrogen sulphide and sulphur dioxide, if present, must be corrected for.

The determination of methane is best carried out on the residual gas from the carbon dioxide determination, although, if desired, a fresh portion may be taken. Two methods recommend themselves for this purpose. In the first,[9] or Winkler's method, the methane is slowly oxidized by means of a heated platinum helix and atmospheric oxygen. In the second it is oxidized by contact with heated copper oxide, independent of atmospheric oxygen.

If the first method is to be pursued the original stopper is replaced by one carrying two brass rods, the transfer being made while the flask is held inverted with its mouth just under water. These rods extend within about 5 cm. of the bottom of the flask, and are joined at their inner extremities by a piece of platinum wire 0.35 mm. in diameter and 7 cm. long, bent in the form of a helix. The outer extremities are connected with a source of electricity. The flask is inverted and held in this position entirely submerged in a bath of cold water. A current of electricity is now passed through the apparatus sufficient to raise the platinum wire to a dull red heat. It is gradually increased during a half hour to about 9 amperes, or sufficient to bring the platinum to incipient whiteness. At the expiration of this period the current is broken, the flask removed from the water, the stopper used in the carbon dioxide method substituted for the one bearing the brass rods, and the carbon dioxide formed by the combustion of the methane is determined as previously described. In this case, however, each c.c. of oxalic acid consumed is equivalent to 1 c.c. of methane, measured under normal

[8] *Proc. Chem. Soc.*, 1896, 192.

[9] Examination of Mine Air, Foster and Haldane, p. 52.
Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 156.

conditions. This method has many drawbacks. Heat enough is often generated to develop pressure sufficient to cause leakage of gas around the stopper, to blow the stopper out or to burst the flask. The flask may be subjected to such unequal heating as to cause it to crack spontaneously. It is always possible that traces of methane may escape oxidation. Moreover, if the percentage of methane be high, as in the analysis of fire damp, or if the percentage of oxygen be low, as in the analysis of black damp, it is necessary to mix the gas to be analyzed with either pure air or oxygen, an operation which is time-consuming, troublesome, and apt to engender grave errors. Should the percentage of methane fall within explosive limits, the method is entirely inapplicable, as even with dilution there is danger of an explosion. Under ideal conditions the accuracy obtainable by this method is of the same order as that in the carbon dioxide determination.

After a lengthy trial of the first method, the writer has adopted the second, or that of Fresenius modified by Winkler.[10] Either the flask containing the air from the carbon dioxide determination, or one filled with a fresh sample, is arranged so that the contained gas may be displaced by water. The air is led first through a soda lime tube, a calcium chloride tube, and then a combustion tube. This combustion tube is of heavy copper, 45 cm. long and 2 cm. in diameter. It is partly filled with coarse copper oxide, is heated to redness by four Bunsen burners, and is provided, at either end, with an annular copper jacket, about 5 cm. long, through which cold water is circulated. These water jackets cool the perforated rubber stoppers through which the air is led, as well as the copper gauze with which each end of the tube is packed. This gauze serves a double purpose; it holds the copper oxide in place, and, should the gas to be analyzed be explosive, acts as the gauze in a Davy safety lamp, eliminating danger from this source. The air, on leaving the combustion tube, is passed through two 200 c.c. Erlenmeyer flasks. These flasks contain a known volume of barium hydroxide solution, of the same strength as used in the determination of carbon dioxide, and a few drops of phenolphthalein. After the sample of air has passed through the combustion train, an operation requiring about 35

[10] Handbook of Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 164.

minutes, the flask in which it was originally contained is removed, and air from without the building is aspirated through the apparatus for about 25 minutes. The two absorption flasks are removed, their contents combined and titrated with oxalic acid as in the determination of carbon dioxide. This method will give accurate results irrespective of the proportion of oxygen or methane in the original sample. The copper oxide in the tube is regenerated by the passage of air after the gas sample, thus leaving the tube in good condition for the next determination. It is important that the air samples should not be passed through the apparatus too rapidly, and that a notable excess of barium hydroxide be maintained in the absorption flask. The barium hydroxide is therefore tinted with phenolphthalein to give warning of its depletion.

It might be well to review some considerations governing these methods. In correcting the volume of the sample in the flask, if the residual air from the carbon dioxide determination be used, both the volume of barium hydroxide and oxalic acid used in the carbon dioxide determination must be deducted before reducing the air volume to normal conditions. In the first method, when calculating the volume of air in the flask an additional deduction must be made for barium hydroxide added and for the volume of the brass rod electrodes. Of course, in the second method this correction does not apply. In determining methane by the first method, on a sample of air from which carbon dioxide has not been removed, the percentage of carbon dioxide in the air must be deducted from the percentage of methane found. This correction is unnecesssary in the second method, as all carbon dioxide is removed by the soda lime tube. In both methods the percentage of carbon monoxide in the air must be deducted from the percentage of methane found, as one volume of carbon monoxide burns to one volume of carbon dioxide as does one volume of methane. In the first method hydrogen sulphide and sulphur dioxide, if present, must also be corrected for.

The accurate determination of even traces of carbon monoxide is of paramount importance. This fact, coupled with the chemical properties of the gas itself, renders recourse to special methods necessary. The well-known unreliability of the methods

based on its absorption by solutions containing cuprous chloride forbids even the thought of their application here. Haldane[11] has endeavored to apply the well-known gas volumetric method based upon the changes of volume occurring when this gas is burned and when the resultant carbon dioxide is absorbed. As has been noted, however, such methods, through inherent weakness, would seem to fall far short of giving the desired accuracy. There is, moreover, nothing positive about these methods. For this reason the so-called blood-test[12] has found considerable favor. In this test advantage is taken of the pink color given to dilute solutions of blood by carbon monoxide hemoglobin. This test, when properly performed by an experienced operator, gives qualitative indications of undoubted value. The personal equation, however, plays too prominent a rôle to permit of its quantitative application, though much has been written to the contrary. If the blood solution containing carbon monoxide be examined spectroscopically[13] the indications are said to become quantitative, however, this method having a wide application in the field of forensic chemistry. Apropos of the qualitative value of the blood-test, another well-known qualitative test might be mentioned. This consists in passing the air to be examined through a solution of sodium cuprous chloride, diluting somewhat and adding a few drops of sodium palladious chloride,[14] when, if carbon monoxide be present, a black precipitate should be formed. This test may be varied by passing the air through a small quantity of water containing strips of filter paper moistened with palladious chloride,[15] the paper blackening in the presence of this gas. A quantitative variation based upon these reactions has been brought forward by Potain[16] and Drouin. The detection of carbon monoxide by any of these alter-

[11] The Investigation of Mine Air, Foster and Haldane, p. 98.

[12] *Loc. cit.*, p. 147.

Trans. Inst. Min. Eng., vol. 11, p. 502.

Trans. Inst. Min. Eng., vol. 38, p. 267, Haldane and Douglas.

Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 892.

[13] A Text-book of Legal Medicine and Toxicology, Peterson and Haines, vol. 2, p. 658.

Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 890.

[14] Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 74.

[15] Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 889.

[16] *Comptes rend.*, 1898, vol. 126, p. 938.

natives is, however, unsatisfactory, as too great a volume of air is required for convenience, and there are many interfering substances. A method has been devised by Spitta,[17] in which the carbon dioxide produced by the combustion of carbon monoxide by silver electrodes, coated with palladium and heated to 150° to 160° C., is determined by Pettenkofer's method. This method is said to be applicable in presence of hydrocarbons, and to possess considerable accuracy.

Probably the methods best adapted to the determination of carbon monoxide in mine air are based upon its oxidation by iodine pentoxide, as pointed out by de la Harte and Reverdine.[18] This reaction proceeds as follows: $5CO + I_2O_5 = 5CO_2 + I_2$, and is quantitative at from 150° to 160° C. If this latter temperature be not exceeded, methane and hydrogen have no action on the reagent, though hydrocarbons of the ethylene and acetylene series are attacked. As the latter gases occur but rarely in appreciable proportions in mine atmospheres, their action may generally be neglected. Hydrogen sulphide and sulphur dioxide might also interfere, but may be readily removed. Many different applications of this method have been brought forward. Gautier [19] absorbs the carbon dioxide formed, and measures its volume after liberation by acid. The same author [20] bases a gravimetric method upon the absorption of the iodine by spongy copper. Nicloux,[21] working at the same time as Gautier, though independent of him, has published a procedure in which the amount of iodine evolved is determined colorimetrically after solution in chloroform. Fillinger [22] has described an apparatus brought forward by Molterski and Norwicki, in which, after removal of the free iodine by metallic silver, the carbon dioxide generated is determined by Pettenkofer's method. A method in which the liberated iodine is absorbed by a solution of potassium iodide, and subsequently titrated with N/1000

[17] *Arch. Hygiene*, 46, 284.
Jour. Soc. Chem. Ind., 1903, 22, p. 652.
[18] *Chem. Zeit.*, 1888, vol. 12, p. 1726.
[19] *Comptes rend.*, 1898, vol. 126, p. 931.
[20] *Comptes rend.*, 1898, vol. 126, p. 1299.
[21] *Comptes rend.*, 1898, vol. 126, p. 746.
[22] *Osterreichische zeitschrift für Berg und Huttenwesen*, 1903, vol. 51, pp. 216, 217.

sodium thiosulphate, has been described in an excellent paper by Kinnicutt[23] and Sanford. In this paper the experimental error of the method was shown to be from ± 0.001 per cent. to 0.0027 per cent., when the carbon monoxide present in the gas varied from 0.023 per cent. to 0.041 per cent., the error, of course, depending on the proportion of carbon monoxide. Their procedure, with slight modifications by the author, may be thus described:

One of the copper sample cans containing the air to be analyzed is placed in a vertical position, and so arranged that water, at room temperature, may be admitted through the bottom tap. The air thus displaced passes through the upper tap to a U tube, the first leg of which contains calcium chloride, the other soda lime. It then passes through a small U tube, containing about 25 gm. of iodine pentoxide, mixed with sufficient glass wool or asbestos to render it porous. From this tube the air passes to a Bowen absorption tube containing about 5 c.c. of 10 per cent. potassium iodide. The tube containing the iodine pentoxide is surrounded by a sand bath, the temperature of which is held between 150° and 160° C. The sample of mine air is passed through the apparatus at a rate of about 1 litre per hour. One litre of air is the quantity usually used, though more may be taken if desired. After the requisite quantity of air has been passed through the apparatus the lower cock of the sample can is closed, and when the bubbles cease to pass through the absorption tube the upper cock is closed and the can is removed. An aspirator is attached to the absorption tube and a slow current of air from outside the building is drawn through the apparatus for about one-half hour. The absorption tube is then removed, its contents rinsed out with distilled water, and titrated with N/1000 sodium thiosulphate, with the addition of a little starch liquor. Each c.c. of the thiosulphate required is equivalent to 0.056 c.c. of carbon monoxide, measured under normal conditions. The quantity of air which has been passed through the apparatus may be determined by measuring the quantity of water in the sample can, or by noting the increase in weight of the can. The volume of air thus determined must be reduced to normal conditions.

[23] *Jour. Amer. Chem. Soc.*, 1900, vol. 22, p. 14.

In their paper Kinnicutt and Sanford purify the air before bringing it into contact with the iodine pentoxide, by passing it first through concentrated sulphuric acid and then over solid potassium hydroxide. This procedure is said to eliminate interfering unsaturated hydrocarbons. As the presence of such in mine air is problematic, as the sulphuric acid, owing to its contamination by organic matter, is apt to generate sulphur dioxide, and as the back pressure of the column of acid would have to be allowed for in computing the volume of air used in analysis, the simpler combination described has been substituted, the function of which is to remove hydrogen sulphide, sulphur dioxide, and water vapor. Should the presence of ethylenes or acetylenes be suspected, the former method may be desirable. These writers, in their work, used an oil bath. It has been found, however, that such baths are not applicable here, as the oil creeps and on coming in contact with the iodine pentoxide liberates iodine. It is important to keep the volume of the purifying tube as small as possible, as less air is thus required to sweep the apparatus clean. It is not practicable to use the air of the laboratory for this sweeping out, as it generally contains sufficient carbon monoxide from leakage of illuminating gas to vitiate the results. The apparatus throughout should be glass-stoppered, and all connections should be of glass tubing, held firmly with glass against glass, so that there is as little contact as possible with rubber. The weak standard sodium thiosulphate is far from stable. For this reason it is best to prepare a N/10 solution and to dilute 10 c.c. of this to 1 litre as required.

Of the many methods proposed for the estimation of oxygen, two have stood the test of long usage. In the first the oxygen is absorbed by a solution of pyrogallol [24] in strong potassium hydroxide. In the second the slow combustion of phosphorus [25] at room temperature is utilized. While these methods are so well known that their description is unnecessary, a few remarks

[24] Handbook of Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 70.
The Investigation of Mine Air, Foster and Haldane, p. 32.
Methods of Gas Analysis, Hempel, 3d ed., p. 149.

[25] Handbook of Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 68.
The Investigation of Mine Air, Foster and Haldane, pp. 7, 31.
Methods of Gas Analysis, Hempel, 3d ed., p. 155.

concerning the applicability of each might be acceptable. The pyrogallate method gives results of unquestionable accuracy when properly carried out. The solution, however, due to its causticity, is unpleasant to handle. It, moreover, deteriorates rapidly, and there is therefore some uncertainty as to the efficiency of a previously-used solution. The advantage of the method lies in the fact that other gases do not interfere with the absorption of oxygen.

In the phosphorus method the pipette containing the reagent must have a temperature of at least 18° or 20° C., the absorption being very slow below this point, almost ceasing, indeed, at 7°. In the presence of certain gases the action of the phosphorus is prevented. Brunck[26] states that the absorption is not rendered slower or less complete by the disturbing gases, but that if white fumes are evolved on bringing the air to be analyzed in contact with phosphorus the reaction will be quantitative. The writer has not met with a sample of mine air to which the phosphorus method was inapplicable. Should difficulties be encountered, however, the former method will be found satisfactory. The advantages of the latter method are its cleanliness, rapidity, and accuracy. An apparatus when once set up can be used for years without renewal of the reagent. The Lindemann[27]-Winkler apparatus will be found convenient, as it is self-contained, requires little manipulation, and may be carried into the mine when desired. With this apparatus results should be obtained differing by not more than 0.1 per cent.

Nitrogen is always determined by difference.

Hydrogen sulphide and sulphur dioxide are generally detected by their odor. It is better, however, in the case of hydrogen sulphide to use strips of alkaline lead acetate paper, as the olfactory organs are apt to become untrustworthy. Quantitatively it may be determined by the depth of color produced when a known volume of air is passed over lead acetate paper,[28] or by passing the air through a solution of iodine and volumetrically determining the iodine consumed by black titration with sodium thiosul-

[26] The Investigation of Mine Air, Foster and Haldane, p. 8.
[27] Technical Gas Analysis, Winkler and Lunge, 2d ed., p. 92. The Investigation of Mine Air, Foster and Haldane, p. 39.
[28] Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 888.

phate.[29] Sulphur dioxide may be determined iodimetrically[30] as just mentioned, or may be weighed as barium sulphate[31] after oxidation with hydrogen peroxide.

The results of an analysis of mine air for ready interpretation are stated in two forms. The values found for oxygen, nitrogen, carbon dioxide, carbon monoxide, and methane comprise the first. The percentage of normal air is then calculated by multiplying the percentage of oxygen found by 100, dividing by 20.93. This value is termed "air." Methane is reported as "fire damp" and carbon monoxide as "white damp." The percentage of carbon dioxide less 0.03 per cent. is termed "excess carbon dioxide." 100 per cent. less the sum of the percentage of "air," "excess carbon dioxide," carbon monoxide, and methane gives the "excess nitrogen." It is often convenient to term the combined values for "excess carbon dioxide" and "excess nitrogen"—"black damp." The second statement of results will therefore contain the figures for "air," "fire damp," "white damp," and "black damp."

The intelligent interpretation of an analysis of mine air requires a knowledge of the sources, physical and chemical characteristics, and physiological action of the various gases determined. As this information is scattered through a great volume of literature, an effort will be made to give a brief *résumé* of the more important data.

In the past it has been customary to divide atmospheres into two classes: extinctive and non-extinctive. This classification, however, is purely arbitrary, being based upon the effect of the air upon the miner's lamp or candle. It is well known that, as the percentage of oxygen in an atmosphere falls, a point is reached at which the ordinary wick-fed flame is extinguished. If, however, the flame is gas-fed and burns from a jet, the point at which it will be extinguished is variable, depending entirely upon the nature of the gas burning. Professor Clowes[32] has

[29] Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 888.
[30] Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 886.
[31] Technical Methods of Chemical Analysis, Lunge, vol. 1, p. 886.
[32] *Trans. Inst. Min. Eng.*, vol. 9, p. 376.
Proc. Royal Soc., vol. 56, 1894, p. 2.
Trans. Inst. Min. Eng., vol. 7, p. 419.

published a classic work on this subject, from which the following table has been taken.

TABLE III.

COMPOSITION OF THE RESIDUAL ATMOSPHERES AND OF THE ARTIFICIAL ATMOSPHERES WHICH EXTINGUISH FLAMES, AND OF AIR EXPIRED FROM THE LUNGS.

Combustible substances burnt	Percentage composition of the residual atmospheres in which the flame was extinguished			Proportions per cent. of O_2 and N_2 in which flame is extinguished when introduced	
	O_2	N_2	CO_2	O_2	N_2
I.					
Alcohol, absolute	14.9	80.7	4.35	16.6	83.4
Alcohol, methylated	15.6	80.25	4.14	17.2	82.8
Paraffin lamp oil	16.6	80.4	3.0	16.2	83.8
Colza and Paraffin	16.4	80.5	3.1	16.4	83.6
Candle	15.7	81.1	3.2	16.4	83.6
II.					
Hydrogen	5.5	94.5	....	6.3	93.7
Carbon Monoxide	13.35	74.4	12.25	15.1	84.9
Methane	15.6	82.1	2.3	17.4	82.6
Ethylene (failed)	....	....	....	13.2	86.8
Coal Gas	11.35	83.75	4.9	11.3	88.7
III.					
Expired Air (average)	16.15	79.9	3.95	....	....
Fresh Air (average)	20.9	79.06	0.04	....	....

Though much stress has been laid upon the extinction of a lamp flame by a vitiated atmosphere, the principal importance of the phenomenon lies in the warning it gives to the miner that there is danger of the air becoming so vitiated as to no longer support life. If we go further into the matter, however, this property becomes of paramount importance; instead of being a source of danger, it becomes one of the most efficient weapons at our disposal in fighting mine fires. In this connection it might be well to note a popular misconception of the *modus operandi* of the extinctive atmosphere. For some reason it is generally supposed that such an atmosphere has a quenching action similar to water upon a fire. This, of course, is not the case. As the percentage of oxygen in the air feeding a fire drops, the rate of combustion decreases, and with it the quantity of heat developed during a given time. Thus when a certain percentage of oxygen is reached the rate of evolution of heat becomes less

than the rate of loss of heat, the temperature of the burning body falling until a point is reached at which re-ignition cannot take place. At this point the fire is said to be extinguished. It will thus be seen that the time required to smother a fire by cutting off its air supply is as much dependent upon the mass of the burning material and the nature of the conducting material surrounding it as upon the composition of the air.

As at present there seems no satisfactory classification of various atmospheres considered as a whole, and as these atmospheres generally differ only in the proportion of their constituents, the sources, properties, and physiological actions of these constituents will be briefly noted.

The general properties of oxygen are too well known to be given space here, though a few words may be devoted to its action on man. The mechanics of the absorption of oxygen by the hemoglobin, and its distribution through the tissues by this medium, is well understood. Normally the human organism is supposed to operate on air containing about 21 per cent. of oxygen. It is remarkable, however, how adaptable this organism is to divergences from this percentage. For some reason general credence has been given to the statement that if air rich in oxygen be breathed for any length of time an exhilaration will be experienced which, if the inhalation be continued, will verge into a delirium resembling alcoholic intoxication. Professor Leonard Hill,[83] quoting the work of Bornstein, Lorain Smith, J. J. R. Macleod, and himself, states that concentrations of oxygen up to 100 per cent. can be borne for long periods without ill effect. The writer has personally administered fairly pure oxygen to men many hundreds of times, and has in no case observed any disturbance of function in the subject.

The question of the effect of an insufficiency of oxygen has been ably treated by Haldane[84] and Lorain Smith. These phenomena, however, are generally considered under the action of black damp and fire damp, but as both these gases are inert their effects are largely due to the lack of oxygen which they displace. In mines a deficiency of oxygen may arise, either from under-

[83] *Trans. Inst. Min. Eng.*, vol. 35, p. 25.
Proc. Royal Sanitary Inst., 1911.
[84] *Journal of Pathology and Bacteriology*, vol. 1, p. 168.

ground fires or, in the absence of fire, from the direct combination of the atmospheric oxygen with the constituents of the coal. Haldane[35] states that "a person not exerting himself will as a rule not notice anything unusual until the oxygen percentage has fallen to 10 per cent. The breathing then usually begins to become deeper and more frequent, the pulse more frequent, and the face somewhat dusky. At 7 per cent. there is usually distinct panting, accompanied by palpitations, and the face becomes of a leaden-blue color. At the same time the mind becomes confused and the senses dulled, although the person breathing the air may be quite unaware of the fact. Muscular power is also greatly impaired. At a slightly lower percentage there is complete loss of consciousness." Virtually the same statements appear so frequently in the literature that they may be considered to be authoritative. The writer has had the opportunity of witnessing several cases of asphyxia induced by exposure to black damp and fire damp. He has also discussed the matter with many experienced miners who have undergone the same unpleasant ordeal, and there seems to be no doubt that, in addition to the symptoms described above, there is considerable nausea and severe headache, coupled with great lassitude. It must be borne in mind, in discussing the physiological action of a mine atmosphere, that the effect noticed is seldom, if ever, traceable to a single gas, but is the resultant of the effects caused by its various components.

Carbon dioxide is a constant constituent of mine atmospheres. Its presence is traceable to various sources. The most important of these is the coal itself. At ordinary temperatures atmospheric oxygen slowly oxidizes the coal, producing carbon dioxide as one of the products of this oxidation. The respiration of men and animals and the combustion of miners' lamps or candles are less important sources of this gas.

Much stress has been laid in the literature upon the toxicity of carbon dioxide. Though under certain conditions the gas possesses undoubtedly toxic properties, it would seem that in the vast majority of cases the damage done by insufficiency of oxygen has been laid at the door of carbon dioxide. Indeed, there seems to be considerable confusion on this point in the minds of many writers. We read of men being overcome by

[35] Investigations of Mine Air, Foster and Haldane, p. 142.

carbon dioxide when descending into wells, old shafts, or ill-ventilated parts of a mine. In truth, it is difficult to conceive of an atmosphere, barring one synthetically prepared, in which there could be a lethal percentage of carbon dioxide and at the same time sufficient oxygen to support life. It is more reasonable to believe that a primary insufficiency of oxygen in these cases is made more deadly by the carbon dioxide associated with it.

In discussing its physiological action, reference must again be made to the classic work of Dr. Haldane, who has described with clarity and elegance the mechanics of the metabolism of this gas. Indeed, the matter has been so ably treated that the writer can do not better than to quote from this authority:[36]

"Mr. Priestley and the writer have shown that at ordinary atmospheric pressure the breathing always regulates itself in such a way as to keep the percentage of carbonic acid in the air cells (alveoli) of the lungs constant. Each individual has his own exact percentage; but on an average there is about 5.6 per cent. of carbonic acid in the aveolar air of man. The regulation is almost astoundingly exact for each person.

"If air containing carbonic acid is breathed, the respirations become deeper, in such a way that the alveolar carbonic acid percentage still remains practically the same, if possible. If, for instance, there is 2 per cent. of carbonic acid in the air, the breathing will need to be about 50 per cent. deeper than before. This difference would not be noticed by the person, but is easily detected by measurement. If there is 5 per cent. of carbonic acid in the air, it requires much panting to keep the alveolar carbonic acid percentage nearly constant; if there is 6 or 7 per cent., it is, of course, quite impossible to maintain a normal alveolar carbonic acid percentage, and great distress is produced, as the blood becomes abnormally charged with carbonic acid, to which the body is exquisitely sensitive. If breathing of ordinary pure air is forced, so that the carbonic acid percentage in the alveolar air is abnormally reduced, natural breathing is afterwards suspended for a short time, the condition known as apnœa being produced. It is carbonic acid, and carbonic acid alone, which regulates our breathing under normal conditions. The supposed

[36] *Trans. Inst. Min. Eng.*, vol. 35, p. 303.

ill effects of a small percentage of carbonic acid in the inspired air are wholly imaginary, as a very slight increase in the depth of breathing at once compensates for the extra carbonic acid. Provided that this compensatory effort is practically inappreciable, we may wholly disregard it. To any moderate variations in the oxygen percentage of the inspired or alveolar air there is no corresponding physiological response.

"The writer and Mr. Priestley found that when the atmospheric pressure was varied it was the partial pressure, and not the percentage of carbonic acid, that remained constant in the alveolar air. The percentage varies inversely as the absolute atmospheric pressure, and was thus found to be lower at the bottom than at the top of a mine shaft and lower in compressed air in exact inverse proportion to the increase of absolute pressure. To take extreme values, Dr. Boycott and the author have found 15 per cent. of carbonic acid in the alveolar air when the atmospheric pressure was diminished to nearly a third, some oxygen being, however, added to the air in order to prevent asphyxia from the low partial pressure of oxygen; on the other hand, Drs. Leonard Hill and Greenwood found only 0.9 per cent. of carbonic acid at an absolute pressure of 6 atmospheres. The partial pressure of the carbonic acid was, however, the same in each case."

Thirkell[37] has tabulated the action of carbon dioxide as follows:

TABLE IV.

Percentage of carbon dioxide present.	Effects on man.	Effects on lights.
3.5	Breathing deeper.	Still burns.
6.0	Marked panting.	Still burns.
10.0	Severe distress.	Still burns.
15.0	Partial loss of consciousness.	Extinguished.
25.0	Final death.	Extinguished.

He fails to state, however, whether the percentages of carbon dioxide noted were added to an atmosphere of normal composition or were produced by combustion. It is evident, from

[37] *Trans. Inst. Min. Eng.*, vol. 8, p. 392.

an inspection of the table, that the former hypothesis is the more likely. The consideration of these data may be aided by the statement that the author has analyzed many samples of anthracite mine air, containing from a trace to 10 per cent. of oxygen, in which the carbon dioxide never exceeded 5 per cent.

The presence of carbon monoxide in mine air may be traced to several sources. As it is a product of the incomplete combustion of carbonaceous substances, it is formed by explosions of coal dust or fire damp, by underground fires, and by the detonation of most explosives. It is well known that carbon monoxide is produced when air at ordinary temperature acts upon bituminous coal. It has remained, however, for Mahler[38] and Denet to prove the presence of this gas in mine air from such a source. These writers have found as much as 0.004 per cent. of carbon monoxide in the air of well-ventilated mines. The statement may be found in the literature that this gas is also produced by the decomposition of organic matter other than coal in the mine. As the presence of carbon monoxide has been considered indicative of mine fires, its presence from other causes must be given due weight before forming a definite opinion as to the existence of a fire.

Its principal claim on our attention, however, lies in its physiological action. As this gas is odorless and non-irritant, it may be breathed in considerable quantity without the subject being aware of the fact, the first warning being given by grave functional derangement. Briefly, the mechanics of its action may be thus described: Carbon monoxide, having an affinity for hemoglobin about 200 times greater than that of oxygen, readily replaces the latter in the blood when breathed. As the blood becomes saturated with carbon monoxide its oxygen capacity becomes correspondingly diminished, until it can no longer supply sufficient oxygen to fulfil the requirements of the organism. In addition to this, the gas is said to cause degeneration of the cells of the organism, and thus serious nervous disorders are brought about. Haldane[39] and Douglass state that physical disablement is produced in man when about 50 per cent. of the

[38] *Comptes rend.*, 1910, 151, 645–647.

[39] *Trans. Inst. Min. Eng.*, vol. 38, p. 271.

blood is saturated with carbon monoxide, death occurring when this figure increases to 80 per cent.

Owing to its great affinity for carbon monoxide, the blood may become saturated to a dangerous extent when this gas is present even in minute quantities. It is difficult to give fixed points at which an atmosphere containing carbon monoxide will produce given effects. It has been stated, however, that quantities under 0.02 per cent. have no appreciable action on man, while the lethal percentage has been fixed at 0.5 per cent. Herman[40] has tabulated the action of carbon monoxide as follows:

TABLE V.

Percentage present in air.	Effects on man.
0.05	After half an hour or more, giddiness on exertion.
0.1	After half an hour or more, inability to walk.
0.2	After half an hour or more, loss of consciousness and perhaps final death.
1.0	After a few minutes, loss of consciousness and final death.

When any given percentage of carbon monoxide is breathed, the blood tends to reach a degree of saturation at which the carbon monoxide and oxygen in the air are in equilibrium with the carbon monoxide in the blood. If we apply the law of Mass Action to this phenomenon, it will be readily seen that a change in the proportion of oxygen will have an effect upon the system, carbon monoxide-oxygen-carbon monoxide hemoglobin, opposite in direction to that produced by a change in the proportion of the carbon monoxide. Now the data on which the statements as to its toxicity have been based have all been gathered when carbon monoxide was breathed mixed with air containing 21 per cent. of oxygen. Unfortunately, however, when carbon monoxide is met with in dangerous quantities in the mines, the oxygen percentage is, as a rule, far below the normal. It seems to the writer, therefore, that under such conditions far lower proportions of carbon monoxide than those noted would produce

[40] *Jour. Soc. Chem. Ind.*, vol. 15, p. 857.

serious results. It is regrettable that we have but little real data bearing on this point. A case has been reported,[41] however, in which several men lost their lives on entering an atmosphere containing 0.0023 per cent. of carbon monoxide and 4.874 per cent. of carbon dioxide. The oxygen percentage was not stated. As has been mentioned before, when considering the toxicity of an atmosphere, the action of no one of its constituents can be taken alone, but all must be considered together.

As carbon monoxide is a poison for warm-blooded animals generally, its effect upon birds and mice has been taken advantage of to give warning of its presence. Haldane,[42] who has been instrumental in bringing this test to the notice of mining engineers, uses these words in describing it:

"The principle of the test is as follows: In small warm-blooded animals the rate at which chemical changes occur in a given body-weight is enormously greater than in large animals. Thus a mouse weighing about half an ounce consumes about fifteen times as much oxygen as half an ounce of the human body would consume in the same time. A reason for this difference is evident enough with bodies of the same shape and composition, but different sizes; the surface increases as the square of any corresponding diameter, but the mass as the cube. The bigger an animal is, therefore, the less surface will it have for a given mass, and the less rapidly will a given mass of it lose heat to the environment; or the less heat, and consequently the less oxygen, will a given mass of it require in order to maintain the normal body-temperature. Not only are the chemical changes in the small animal far more rapid, but the rate of respiration, circulation, etc., are correspondingly increased. It is difficult to count by the eye the rate of breathing in a mouse, and quite impossible to count its pulse-rate. By a photographic method of recording the electrical changes which accompany the heart-beat, Miss F. Buchanan, of Oxford, has recently shown that the pulse-rate in mice and small birds is from 700 to 1000 per minute.

"It follows that the small animal will absorb any poisonous gas far more quickly than a man will, and will therefore show symp-

[41] *Trans. Inst. Min. Eng.*, vol. 34, p. 564.
[42] *Trans. Inst. Min. Eng.*, vol. 38, p. 270.

toms of poisoning far sooner. It can, in fact, be employed to show what will ultimately happen to a man if he remains in the poisonous air. This, and this alone, is the principle of the test. The small animal is not, in the long run, more sensitive than a man to a given percentage of carbon monoxide; indeed, the opposite is almost certainly the case."

The symptoms of poisoning by this gas are varied. When small quantities are breathed there may be drumming in the ears, with more or less frontal headache and nausea. As the poisoning proceeds, giddiness and lassitude will set in, followed by progressive loss of power in the lower extremities, merging into paralysis, which eventually invades the rest of the body. Synchronously with loss of muscular power the mental processes become deranged. Should the subject, however, inhale an atmosphere containing much carbon monoxide, almost instant insensibility will be the result. After recovery from exposure to this gas, severe pains in the head and extremities have been frequently noted, though a more serious after-effect is pneumonia.

The post-mortem appearances are characteristic. As carbon monoxide hemoglobin possesses a deep violet to cherry-red color, the face and lips have a remarkably fresh and lifelike appearance, very different from the bluish or livid pallor produced by a deficiency in oxygen.

Methane, the principal constituent of fire damp, is never found in the pure state. Beside the other components of an atmosphere, it is now generally conceded that it is accompanied by small proportions of higher hydrocarbons of the same, and unsaturated series. As these other hydrocarbons exert but little influence upon the properties of methane, their presence is more of academic than real interest. The gas is colorless, odorless, and lighter than air. Dickson and Coward give its ignition temperature in air at from 650° to 750°C. Air containing from 5 per cent. to 16 per cent. of methane will explode on ignition, though outside of these limits it may be dangerous because of its inflammability. It has been conclusively shown that methane finds its way into the air of a mine not only from reservoirs of the gas under pressure, but also more gradually from the coal substance itself. Though, as already pointed out, methane has in itself

no physiological action, its indirect effect upon man through the dilution of oxygen which it brings about may be thus indicated:

TABLE VI.[44]

Percentage of fire damp present.	Effects on man.	Effects on lights.
1.0	Nil.	First indication of a cap.
2.0	Nil.	Well-formed cap.
5.5	Nil.	Lamp fires and goes out.
45.0	Breathing slightly deeper.	Lamp fires and goes out.
70.0	Life endangered.	Lamp fires and goes out.

An excess of nitrogen in mine air is due principally to the abstraction of oxygen by oxidizable substances. Black damp of this variety is distinguished by its lightness, being found in caps similar to fire damp, and is sometimes designated as "light air." Like methane, it is inert physiologically, acting merely as a diluent. Its action when carrying some carbon dioxide has been thus stated:

TABLE VII.[45]

Percentage of black damp (containing 87 per cent. of nitrogen and 13 per cent. of carbon dioxide) present.	Effects on man.	Effects on lights.
16	Nil.	Extinguished.
28	Breathing slightly deeper.	Extinguished.
50	Severe panting.	Extinguished.
66	Life edangered.	Extinguished.

Nitrogen peroxide is one of the products of the combustion of certain explosives. It is extremely poisonous when breathed. Peterson and Haines[46] state: "Habitually breathed in small quantities and great dilution, it produces severe chronic diseases. In acute poisoning, immediate dyspnea, tightness of chest, coughing, fainting, cyanosis, diarrhœa, and collapse. Death within forty hours, though symptoms of slight poisoning are delayed, in which case the first symptoms are headache, desire for fresh air, thirst, and then suddenly symptoms of aggravated character—distress of breathing, anxiety depicted on face, cold per-

[44] *Trans. Inst. Min. Eng.*, vol. 13, p. 393.
[45] *Trans. Inst. Min. Eng.*, vol. 13, p. 393.
[46] Text-book of Legal Medicine and Toxicology, vol. 2, p. 676.

spiration, protruding eyeballs, and spasmodic coughing, followed by vomiting."

The presence of hydrogen sulphide in mine air may be brought about by the bacterial decomposition of organic matter, by the heating of coal by a mine fire, or by the action of organic matter on sulphates in solution. It is slightly heavier than air and possesses a strong odor, 0.01 per cent. being readily detected by the olfactory organ. This gas is even more toxic than carbon monoxide; it is stated that as little as 0.02 per cent. may have a toxic effect. Birds are especially sensitive to it, being killed by 0.05 per cent. "Breathed [47] in its pure state, this gas is immediately fatal. It acts upon all animals through all tissues, especially the lungs. If somewhat diluted, it produces nausea, giddiness, cold skin, labored breathing, irregular action of the heart, pains in the stomach, and death by coma or in violent convulsions, with tetanus and even delirium. In greater dilution sleepiness will be produced, the continued respiration of the gas proving fatal, sensibility not being restored. In exceedingly dilute condition it sometimes occasions febrile symptoms somewhat resembling typhoid. Air containing 0.05 per cent. was the limit that men could breathe (Lehmann). Sometimes symptoms appear after a considerable lapse of time after breathing the gas, and they may continue for some days."

The presence of sulphur dioxide is probably one of the surest indications we have of the presence of a mine fire. Fortunately the gas is so suffocating that ample warning is given of its presence. Though notably toxic in its action, workmen exposed to the gas may establish considerable tolerance toward it.

One plan of treatment is indicated for asphyxia brought about by the gases already described, except in the case of nitrogen peroxide, hydrogen sulphide, and sulphur dioxide. The victim should at once be brought into the fresh air, and artificial respiration by either the Sylvester or Shafer methods applied. If possible, a supply of pure oxygen should be used as an adjunct to the artificial respiration. Recently two apparatuses, the "Brat" and "Draeger Pulmotor," have been devised, with which air containing a high percentage of oxygen is forced into the lungs at a slight pressure, and then exhausted until a slight vacuum is

[47] *Loc. cit.*, p. 671.

TABLE VIII.

COMPARISON OF THE PHYSIOLOGICAL ACTION OF AIR CONTAINING VARIOUS POISONS (LEHMANN).

The results are given in some cases in volumes p. ct. and in others in milligrams per litre	Quantity causing rapid death	Concentration which in ½ to 1 hour causes illness and danger to life	Concentration which produces no serious effect in ½ to 1 hour	Concentration which gives only slight symptoms after several hrs.	Author and reference
Hydrochloric acid gas.	....	0.15–0.20%	0.005 or at most 0.01%	0.001%	K. B Lehmann, Arch. f. Hyg. 5; Matt, Diss, Wurzburg, 1889.
Sulphurous acid.....	....	0.04–0.05%	0.005%	0.002–0.003%	Orgata, Arch. f. Hygiene, 19. K. B. Lehmann and Wagschal (Dissertation).
Hydrocyanic acid.....	about 0.03%	0.012–0.015%	0.005–0.006%	0.002–0.004%	K. B. Lehmann and Wagschal (Dissertation).
Carbon dioxide.....	30%	about 6.0–8.0%	4.0–6.0%	2.0–3.0%	Emmerich, Friedlander and Herlerz. physiolog. Chem. 2.
Ammonia.....	....	0.25–0.45%	0.03%	0.01%	K. B. Lehmann, Arch. f. Hygiene, 5; 34.
Chlorine and bromine.	about 0.1%	0.004–0.006%	0.0004%	0.0001%	K. B. Lehmann, Arch. f. Hygiene, 7; Matt, loc. cit.
Iodine.....	....	....	0.0003%	0.00005–0.0001%	Matt, loc. cit.
Phosphorus trichloride	3.5 mg.	0.3–0.5 mg.	0.01–0.02 mg.	0.004 mg.*	K. B. Lehmann and Butjegin, Arch. f. Hygiene, 14.
Hydrogen phosphide..	....	0.04–0.06%	0.01–0.02%	....	K. B. Lehmann and Yokote, Arch. f. Hygiene, 14.
Hydrogen sulphide...	0.1–0.2%	0.05–0.07%	0.02–0.03%	0.01–0.015%	K. B. Lehmann, Arch. f. Hyg. 14.
Petroleum vapor.....	....	....	15–25 mg.	5–10 mg.	
Benzene.....	....	....	10–15 mg.	about 5 mg.	
Carbon bisulphide....	....	10–12 mg.	2–3 mg.	1–1.2 mg.	K. B. Lehmann, Arch. f. Hyg. 14.
Carbon tetrachloride..	300–400	about 150–200 mg.	about 25–40 mg.	about 10 mg.	K. B. Lehmann and Behr (Dissertation).
Chloroform.....	300–400	70	25–30 mg.	about 10 mg.	K. B. Lehmann and Behr (Dissertation).
Carbon monoxide.....	....	0.2–0.3%	0.05–0.1%	0.02%	Max Gruber, Arch. f. Hyg. 2.
Aniline and toluidine..	....	....	0.4–0.6 mg.†	0.1–0.25 mg.	K. B. Lehmann and Flogel (Dissertation).
Nitrobenzene.....	....	....	1.0 mg.‡	0.2–0.4 mg.	K. B. Lehmann and Zieger (Dissertation).

* Even as small a quantity as 0.0025 per cent. taken for about six hours per day sufficed to produce certain death.
† Quantities over 0.8 mg. per litre generally kill cats, if taken for more than five hours. Toluidine is somewhat less poisonous.
‡ The maximum quantity of nitrobenzene which can be brought into the air is about 1 mg. per litre; it never acts as a powerful poison when inhaled.

attained. With these latter appliances, of course, artificial respiration is unnecessary. The main difference between the Brat and the Draeger apparatus lies in the fact that the former is manipulated by taps under the control of the operator, while the latter is automatic in its action. The writer has had the opportunity, on various occasions, to apply these methods in cases of asphyxia, with most gratifying results. It is indeed remarkable how quickly a man, to all appearance dead, will regain consciousness when supplied with an excess of oxygen.

The primary object of so-called "rescue" or "breathing" apparatus is to permit the wearer to enter, safely and without inconvenience, an atmosphere incapable of supporting life. The various types of apparatus now in use may be divided into three classes: those in which oxygen is chemically generated within the apparatus; those in which liquid air is the source of the oxygen supply; and those in which the respired air is chemically purified or "regenerated," its deficiency in oxygen being made up from tanks of the compressed gas. It would be laborious and time-consuming to trace the gradual growth and improvement of these devices, nor does it lie within the scope of this paper to criticize or compare their commercial variations. Moreover, as the first two classes named have not been generally adopted, their discussion will be omitted. It will therefore be the object of these few closing paragraphs to point out certain desiderata which should be fulfilled by the successful breathing apparatus.

As the breathing apparatus is complementary to the wearer, it is necessary, before fixing conditions which it must fulfil, to understand very clearly the requirements of the wearer under varying working conditions. When a man breathes, the inspired air contains approximately 20.93 per cent. of oxygen, 79.04 per cent. of nitrogen, and 0.03 per cent. of carbon dioxide. About 4.50 per cent. of this oxygen enters into combination with the hemoglobin, being replaced by about 4 per cent. of carbon dioxide, the nitrogen remaining unchanged. Thus the expired air contains roughly 16 per cent. of oxygen, 80 per cent. of nitrogen, and 4 per cent. of carbon dioxide. Haldane[48] and Lorain Smith state that under working conditions a man will require from 50

[48] The Physiological Effects of Air Vitiated by Respiration, *Jour. of Pathology and Bacteriology*, 1892, vol. 1, p. 168.

to 60 litres of air per minute, though for a brief period after severe exertion this figure may reach 100. The author's experience fully bears out this statement. Of course, during periods of rest less than 50 litres of air per minute will be required. The breathing apparatus must therefore supply a minimum of two litres of pure oxygen per minute, must remove the carbon dioxide formed, and must at the same time circulate through the apparatus a minimum of 50 litres of air each minute.

The ideal breathing apparatus should be as light as is compatible with strength and safety, as the wearer is laboring under severe mental stress, abnormal conditions, and oftentimes an insufficient air supply. It must be self-contained; that is, independent of any fixed base. It must permit the wearer to engage in severe muscular effort. The removal of carbon dioxide by the regenerator must be as complete as possible; a maximum of 2 per cent. should not be exceeded. As the fixation of this gas by caustic alkalies generates considerable heat, and as breathing heated air is extremely distressing, the air should pass through an efficient cooler after leaving the regenerator. The energy stored in the compressed oxygen should be utilized in circulating the air through the apparatus, thus relieving the lungs from this duty. A gauge should be provided which shall indicate distinctly and accurately for what length of time the apparatus may be used. The apparatus must be readily recharged. The charges must be so prepared that they may be stored for considerable lengths of time without deterioration. Inhalation and exhalation bags must be provided. The operation of the apparatus must be absolutely automatic, thus leaving the wearer's mind free. As the supply of air is constant, irrespective of the needs of the wearer, during periods of rest, an excess of oxygen will accumulate in the breathing bags. As the back pressure thus produced may cause considerable distress and even danger, a relief valve should be provided. The apparatus must be air-tight as regards the outside air, and must make an air-tight joint at the wearer's face. The wearer's eyes must be protected against smoke or irritant gases.

Breathing apparatus fulfilling most of these requirements has been constructed of two general types. In the one the air is supplied to the wearer through a mouthpiece, the nostrils being closed by a clip. In the other the head is encased by a helmet.

an air-tight joint being made about the face by a pneumatic cushion. There has been much acrimonious discussion in regard to the relative merits of these two types of equipment. It would seem to the writer, however, that there is but little profit in such discussion, as both have their advantages and disadvantages, while each has its own particular sphere of usefulness.

While a great volume of material has been written on the subject of the requirements of a man equipped with breathing apparatus, it has occurred to the author that a most important phase of the matter has been neglected; namely, the insensible respiration. In addition to the oxygen absorbed through the lungs, the blood is continually being supplied with oxygen through the skin. Gerlach[49] states that the ratio of oxygen supplied by the skin to that supplied by the lungs is as 1 is to 137, while Regnault[50] and Reiset set the ratio at 1 to 180. Should the wearer of a breathing apparatus enter an atmosphere low in oxygen, the inconvenience caused by the curtailment of the supply of this gas through the skin would probably be negligible. Should, however, the atmosphere contain much carbon monoxide, there might be considerable cause for apprehension, when we consider that carbon monoxide has over 200 times greater affinity for hemoglobin than oxygen, and practically the same diffusibility through animal membrane. Of course, this danger would only become pressing after long exposure to such an atmosphere. It is for this reason that the writer cannot too strongly urge those who may have direction of rescue parties to expose their men no longer than necessary to lethal atmospheres.

In conclusion the writer wishes to express his deep sense of gratitude to our secretary, Dr. Owens, for the great assistance he has rendered in furnishing data for this paper.

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[49] Die Physiologie der Haut, Roehig, Berlin, 1876.
[50] Human Physiology, Landois and Sterling, London, 2d ed., p. 886.

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THE DETERMINATION OF MOISTURE IN FUEL.

BY

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WHEN purchasing and utilizing coke and coal, the presence of moisture in the material purchased is objectionable for at least two reasons: First, the water is purchased and paid for as carbon; and, second, the water so purchased necessitates the combustion of some of the carbon to drive it off from the fuel bed. Thus we are not only paying for a worthless material as good carbon, but we are penalized as well.

Bituminous coal, and frequently coke, is received at destination in open cars of the gondola type, and in transit is liable to be soaked by heavy rains, sleet, or snow. Usually the shipment is paid for by railroad weights, and if the car was weighed before the contents were water-soaked, the purchaser suffers no loss from the first objection named; he must, however, still encounter the cost of boiling off the water accumulated in transit.

In order to give an idea of the amount of water which some well-known fuels will absorb, samples of oven coke, run-of-mine steam coal, and Fairmount gas coal were subjected to the following test (see Appendix No. 1):

The fuels were wet down with a hose, drained by being placed in perforated galvanized iron pails, and weighed. These pails were then hung in a normal atmosphere at a temperature of 70° F. and weighed at intervals of one day until ten days had expired. The details of this test prove that in the case of oven coke the wet sample lost 14.6 per cent. of its weight, due to the evaporation of the moisture which it originally contained. With the steam coal, the loss was 13.3 per cent.; but with the Fairmount, screened gas coal, the aggregates consisting of clean cubes about egg size, the contained moisture was only 2.2 per cent. Other tests of retort coke from coal gas plants show that this coke will absorb water to the extent of 22 per cent. of its dry weight if exposed to rain.

It is evident, therefore, that unless we have some knowledge

of the content of moisture in the fuel, we may pay 15 per cent. more for a ton of carbon in the case of wet fuel than we do in the case of dry fuel. The significance of this possibility becomes more apparent when we consider the case of a carburetted water gas plant manufacturing 10,000,000 cubic feet of gas a day, with a consumption of 150 tons of coke daily. The value of this dry coke at current prices is $675. If, during the process of quenching, or at any time previous to weighing, it has absorbed 10 per cent. moisture, the increased cost to the gas company over and above what it would pay for dry coke is $75 a day, or, in a year of 365 days, $27,375. In addition to this expense, the cost of boiling off this water from the fuel after it is put into the cupolas will be, in the case of a plant discharging the stack gases at a temperature of 1500° F., 2 per cent. of the total fuel consumed. This would add another expense of $13.50 per day, or $4,927.50 yearly.

Referring again to the test of the various samples of fuel, when soaked with water and allowed to dry, it will be noted that there was a gradual dissipation of the moisture from the start of the test until the end. In other words, if a sample of wet coke or coal is selected at the mines or at the car and transported any appreciable distance or for any considerable time, there will be, if protected from further wetting, a loss of moisture in the sample. To illustrate this, I quote from a letter received from Mr. C. J. Ramsburg, Assistant Engineer of Works of the Philadelphia Gas Works:

> "So far, the use of the moisture determinator has been restricted to the testing of coke receipts, in which we have proved that the laboratory analysis of the coke is no criterion of the condition of the coke as received by us. For example, on October 3d a barge of coke was received, the average sample of which was taken during the unloading, and, tested in the moisture determinator, showed 11.6 per cent. moisture. The analysis of the sample taken at the same time, when conveyed to the laboratory, crushed and sampled according to the usual laboratory system, showed only 2.1 per cent. moisture."

Numerous other instances of the same general nature could be cited.

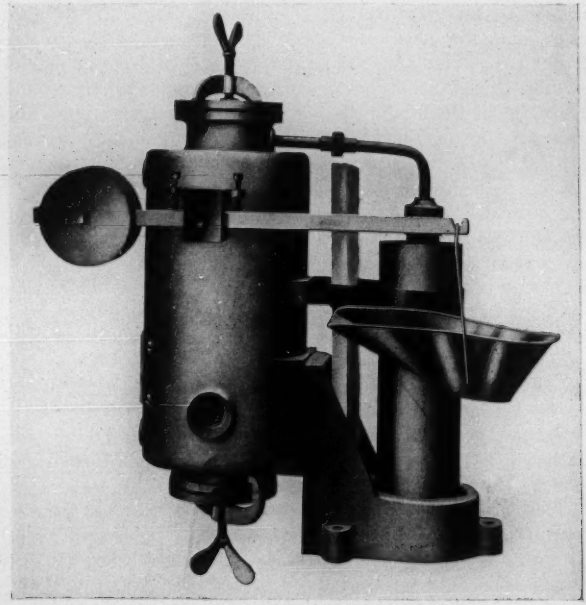
Where very high guarantees are made of the consumption of carbon in water gas apparatus, the determination

of the water in the fuel becomes a very important matter. For example, the presence of 10 per cent. of moisture may readily result in a failure to obtain the guarantee, not only because it interferes with the proper working of the apparatus, but because it is weighed into the apparatus as carbon. Under these circumstances, great difficulty has been experienced in obtaining the content of moisture in the fuel actually charged into the machine, on account of the fact that the laboratory is frequently at a distance from the generating house and considerable time elapses between the taking of the sample and its analysis in the laboratory. These conditions always operate against the guarantor of results, as there is invariably a loss of moisture, where much is present during the transportation and handling of the sample, for which the operator gets no credit. In the standard method of determining moisture in coal and coke, opportunity is also offered for the escape of moisture to the atmosphere after the sample is received at the laboratory and before the determination actually begins. Usually the finely-ground sample is placed in an open porcelain or platinum crucible, weighed, and dried for one hour in any good form of air bath. Upon removal from the oven, the crucible is covered and cooled in a desiccator and again weighed. The loss in weight gives the moisture. It will be noted that before the initial weight is taken the sample has been selected on the generator house floor, transported to the laboratory, and finely ground. During all this period there is a continual loss of moisture, the amount depending somewhat upon the humidity of the atmosphere.

It was on account of the difficulties described above that an effort was made to devise a simple and fairly accurate means of making moisture determinations at the place where the fuel is consumed. The result is the moisture determinator as shown assembled in Fig. 1 and in section in Fig. 2. In this instrument a steam jacket is used to drive off the moisture, the temperature of the jacket being determined by the steam pressure, and maintained at such a point that, while the moisture is driven off, the volatile combustible will be retained in the fuel chamber. *A* is the fuel chamber in which is deposited the sample of fuel to be examined for moisture. Its volume is such as conveniently to hold the ample sample of one pound of the fuel. *B* is a graduated glass tube surrounded by a reservoir *C* containing

cool water, which latter may be introduced at *I* and be removed at *O*, thus forming a condenser. The graduations of the tube *B* are of such magnitude that when 1 per cent. by weight of the sample is driven off in the form of moisture and condensed in the tube the volume of the condensed water vapor driven off

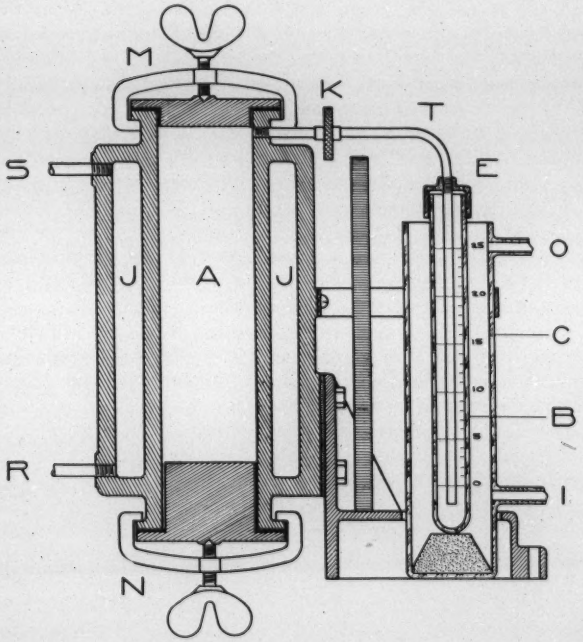
FIG. 1.



will just equal the volume between any two graduations on the tube. Around the chamber *A*, forming a jacket, is the annular space *J*. Into this space steam at any desired temperature is introduced at *S* and discharged at *R*. *M* and *N* are means for filling and emptying the chamber *A*, and *K* is a ground joint union which permits the graduated tube *B* to be disconnected and emptied after the determination is completed. The apparatus is operated as follows:

The determinator may be erected on any convenient wall or table, preferably as close as possible to the point where the fuel is being consumed, thus eliminating to a great degree any change in the moisture content in the sample between the time the sample is taken and the time the moisture content is determined.

FIG. 2.



A balance shown in Fig. 1 is provided with the determinator, by the aid of which one pound of the fuel is introduced into the chamber *A*. Steam is then turned on the jacket *J*, and by the aid of a pressure gauge on the pipe *S* the temperature is maintained at any convenient degree, preferably at 230° F., as at this temperature the water may be driven off

without the volatilization of any of the hydro-carbon vapors. A cock on the discharge pipe *R* should be left slightly open so that any water condensed in the chamber may be carried off, and thus prevent it from affecting the temperature of the jacket. Previous to turning on the steam, water circulation has been started through the receptacle *C* by means of the pipes *I* and *O;* also, sufficient water has been introduced through the hole *E* to bring up the level in the tube *B* to the zero mark. Upon the turning on of the steam through the pipe *S* the determination begins and the instrument may be left without any attention for the space of an hour, when it will be found that practically all of the moisture is driven off from the sample and appears in the tube *B* as water, in per cents. of the original weight of the sample.

In addition to its other merits, the apparatus possesses the following two very important ones:

First: In its use but one weighing—that of the moist sample of fuel—is necessary, and any small error in this weighing can produce only a correspondingly small error in the moisture percentage result; in the ordinary method, on the other hand, two weighings—one of the moist and one of the dry sample—are required, and even a small error in one of these weighings, and consequently in their difference, which is supposed to represent the weight of moisture, may cause a very large error in the determination of percentage of moisture.

Second: The moisture in the fuel is condensed to water, is visible, and hence its existence is indisputable.

Before this instrument was put into service a calculation was made to determine theoretically what would be its characteristic error. This calculation is given in Appendix No. 2, and shows that theoretically the error should be about .13 per cent.; that is, the true content of moisture would be .13 per cent. greater than the indicated content, owing to the volume of the voids in the sample of fuel and of the pores of the coke itself. To check this calculation, definite quantities of moisture were added to dry samples of coke and the samples examined in the determinator, with the result that the practical error agreed with the theoretical error.

Although this instrument was devised particularly for use in

obtaining high guarantees connected with the combustion of coke and coal, it has been found useful in various ways. For instance, in a coal gas plant where the yield of gas, ammonia, tar, etc., per pound of coal is figured in great detail, it is found that the uncertainty introduced by the presence of a variable amount of moisture is very annoying. With the use of the moisture determinator, however, this uncertainty is to a large extent eliminated. In one case it was found that the content of moisture in gas coal as weighed into the bins averaged as high as 9 per cent. for a period of some months. If this content of moisture had not been known, the poor results from the use of such coal would have widely misled the operating engineer.

New uses for this instrument are constantly being suggested, among them the determination of water in metallic ores, and water and light oils in tar. At present it does not seem practicable for everyone to purchase coal on a B. T. U. basis, but the United States Government has adopted this practice, and, as it is without doubt the equitable way of purchasing fuel, we may expect before many years to see it generally adopted. In this case the determination of the moisture in the shipment purchased is of equal importance with the determination of ash and other impurities, and the field of usefulness for the moisture determinator will probably be greatly broadened.

APPENDIX NO. 1.

A. Camden oven coke egg size.
Weight of dry sample..... 9.9 lbs.
B. Quemahoning boiler coal, run-of-mine.
Weight of dry sample..... 16.7 lbs.
C. Fairmount gas coal screened; egg size.
Weight of dry sample..... 16.3 lbs.

	Per cent of Moisture		
Elapsed Time	A.	B.	C.
Start	14.6	13.3	2.2
18 hours	11.3	9.6	1.2
3 days	7.4	5.9	.9
4 days	6.6	4.6	.7
6 days	4.5	2.3	.6
7 days	3.3	1.7	.6
10 days	2.5	1.3	.6

APPENDIX No. 2.

Moisture determinator.

Chamber = 2 – $\frac{7}{8}$″ diam. × 12″ = 6.4918 sq. in. × 12″ = .0451 cu. ft.

Capacity of Chamber: Allowance 37 per. cent. = voids in coke = .0451 cu. ft. × .37 = .0167 cu. ft. = volume containing moisture at finish.

212° F.
459.4
671.4° F. Absolute temp.

80 lbs. press. = 95 lbs. absolute = 323.9° F.
459.4
783.3° F. Abs.

.0167 cu. ft. × $\frac{671.4}{783.3}$ = .0143 cu. ft. steam.

1 cu. ft. steam, atmospheric pressure = .03794 lbs.

.0143 × .03794 = .0005425 lbs. steam remaining at finish of operation.

1 cu. in. H_2O at 60° F. = 16.4 cu. centimetres.

1 cu. in. H_2O at 60° F. = .0361 lbs.

.0005425 lbs. divided by .0361 = .01503 cubic inches.

.01503 cu. in. × 16.4 = .2465 c.c. H_2O remaining at finish, due to voids.

Coke as per sample = 50 per. cent. porosity.
37 per. cent. voids.
87 per. cent. total.

.0451 cu. ft. capacity × .87 = 0.039237 cu. ft. = volume due to porosity and voids = $\frac{.039237}{.0167}$ or 2.35 times the above.

.0005425 lbs. steam remaining × 2.35 = .001275 lbs. steam = $\frac{.001275}{.0361}$ = .03531 cu. in.

.03531 cu. in. × 16.4 c.c. = .579 c.c. H_2O remaining.

1 c.c. H_2O at 60° F. = 1.001 grains × .579 = .5795 grains.

Assumption 1 lb. coke = 453.6 grains gross weight $\frac{.5795}{453.6}$ = .0012775 = .12775 per cent. = Loss.

The Resistance of Iron to Rust in Concrete. ANON. (*Rev. Scientifique*, xlix, 1, 23.)—An old building in Hamburg was recently demolished, from which the behavior of iron enclosed in concrete can be judged. This was an old gasometer, the foundations of which rested on several pillars. The iron anchors were immersed in cement grouted to a good thickness. The 60 bars, each 2½ metres long, which formed the anchors, were examined, and were found to be perfectly well preserved. They still showed their outer bluish skin and no trace of rust. This gasometer was built between 1852 and 1855, so the iron bars had been fully 50 years in the concrete. This protection from rust can be explained by the fact that the dampening of the concrete had produced a strongly alkaline reaction, and that iron, when surrounded by alkali, is inoxidizable.

THE INTERNATIONAL ELECTROTECHNICAL CONGRESS OF TURIN.

A Brief Report to the Franklin Institute, Subject to the Official Reports of the Congress,

BY

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(Harvard University)

An Official Delegate of the Institute.

The International Electrotechnical Congress, which was held at Turin, September 10–17, 1911, was organized under the auspices of the Associazione Elettrotecnica Italiana (A. E. I.) and of the Italian Committee of the International Electrotechnical Commission (I. E. C.), in relation to the Turin-Rome International Industrial Exhibition, which celebrated the semi-centennial anniversary of Italy's political union.

The organization consisted of:

(1) A Committee of Honor, headed by H. R. H. the Duke Degli Abruzzi, and 28 members, principally either officers of the Italian government or of the Turin municipality, but including Prof. Elihu Thomson, the President of the I. E. C.

(2) A Committee of Organization of 30 members, headed by Prof. L. Lombardi, the president of the A. E. I., and comprising the presidents of the various sections of that society, as well as the presidents of the national committees of the I. E. C. An American sub-committee was formed of the following members: J. W. Lieb, Jr. (president), and Messrs. A. E. Kennelly, C. O. Mailloux, T. C. Martin, H. G. Stott, and S. W. Stratton. The Congress secretaries were Messrs. C. A. Curti and G. Semenza.

(3) An Executive Committee of 23 members, headed by Prof. G. Grassi, the president of the Turin Section of the A. E. I., and enrolling a number of active members of that section.

Notice was sent in 1910 to the various national committees of the I. E. C. that the Congress would be divided into eight sections, and offering a list of 31 official electrotechnical subjects, on which reports were requested, in advance, from specialists in the various countries, which reports should be laid before the Congress as the basis of its discussions. Papers were also invited, to be offered for acceptance in advance. The number of such accepted and presented papers amounted to 49, making a total of 80 communications read at the sessions, from writers in 14 different countries, representing 10 different languages. The American communications were 11 in all. The complete series of papers is expected to be printed in the Proceedings of the Congress.

Four official languages were selected—English, French, German, and Italian—in any of which a communication might be offered or a discussion contributed; but English, German, and Italian papers had to be accompanied by a brief French *resumé*. In the official notices and bulletins of the Congress only the French and Italian languages were used, side by side.

The total number of full-membership adhesions to the Congress printed up to September 15 was 453, while the total registrations of all classes exceeded 650.

The following officers were elected at the opening session on September 10:

President—Prof. Luigi Lombardi.

Vice-presidents—Prof. Guido Grassi, Ing. Emanuele Jona.

General Secretary—Ing. Guido Semenza.

Honorary Vice-presidents—

Antonio Pacinotti for Italy.

Silvanus P. Thompson and Alexander Siemens for England.

Gano Dunn, president of the A. I. E. E., for America.

Paul Janet for France.

Karl Strecker for Germany.

Alfred Graf for Austro-Hungary.

Pierre Ossactchy for Russia.

Gustave L'Hoest for Belgium.

Behn-Eschenburg for Switzerland.

De La Pena for Spain.

Poulsen for Denmark.

The following section officers were elected:

Section	*Subject*	*President of Section*	*Vice-Presidents*	*Secretaries*
I.	Electrical Machines and Transformers	BOUCHEROT (Francia)	MORELLI (Italia) FELDMANN (Olanda)	C. PALESTRINO
II.	Electrical Systems and Networks	DE BAST (Belgio)	FERRARIS (Italia) LANDRY (Svizzera)	DEL BUONO BOCCARDO
III.	Instruments and Measurements	KENNELLY (U. S. A.)	DINA (Italia) ARMAGNAT (Francia)	EMANUELI BARBAGELATA
IV.	Lighting and Heating	ROSSANDER (Svezia)	MENGARINI (Italia) SHARP (U. S. A.)	DANIONI
V.	Electric Traction	MAILLOUX (U. S. A.)	SARTORI (Italia) BARNET LYON (Olanda)	FENZI PONTI
VI.	Telegraphy and Telephony	O'MEARA (Inghilterra)	LARSEN (Danimarca) DI PIRRO (Italia)	BELLINI
VII.	Electrochemistry and Metallurgy	BECKMANN (Germania)	MIOLATI (Italia) RUMI (Italia)	
VIII.	Tariffs and Taxation	ARNO (Italia)	DETTMAR (Germania) BONGHI (Italia)	BOTTO GIULIETTI

Certain resolutions were presented by the sections, were printed in the official bulletin, and set for consideration at the plenary sessions of the Congress as a whole. The following is a synopsis of the more important resolutions thus adopted by the Congress at large:

(1) That the International Electrotechnical Commission is requested to accept the task of organizing future electrotechnical congresses, so far as concerns their dates, places of meeting, and objects, the details of the organization of each Congress being confided to the electrotechnical committee of the country in which the congress is to be held, with the assistance of its technical societies if necessary.

(This official request was duly received and accepted by the Council of the I. E. C., in session at Turin, on September 13.)

(2) That the International Electrotechnical Congress of Turin compliments the American Institute of Electrical Engineers on the practice it has adopted of inserting in its publications the metric equivalent value, in parentheses, after each expression of values in English measure.

And since this procedure greatly facilitates the reading of those publications in all the countries using the metric system, while constituting a worthy example towards, and in view of, the much-desired complete international unification of weights and measures;

Resolved, That the technical societies of all countries in which the metric system is not yet official are invited to follow the above-mentioned example of the American Institute of Electrical Engineers.

(3) That industrial traction accelerations be expressed in kilometres per hour per second (or equivalent local national terms, such as miles per hour per second, or versts per hour per second).

(4) That the Congress favors the appointment of an International Commission for the general study of systems of illumination and of all technical problems connected with illumination.

A meeting of the A. E. I. was held on September 13, largely attended by Congress members, to celebrate the semi-centennial anniversary of Signor Pacinotti's invention of his ring-armature for dynamo machines, and to present to him a testimonial of recognition and esteem. President Lombardi presented to Signor Pacinotti a handsomely-illuminated copy of his original paper on the ring-armature machine, originally printed in *Il Nuovo Cimento* for 1865. A brief reply of thanks was made by Signor Pacinotti, which was received with acclamation.

Technical visits were paid by parties of Congress members to electric installations of interest in the vicinity, under the escort of their Italian hosts.

At the closing plenary session of September 16 the thanks of the Congress were voted to the Committee of Organization, and especially to President Lombardi and Secretary Semenza, for their very successfully performed services. The various national delegations joined heartily in these recommendations. The thanks of the Congress were also cordially expressed to the city of Turin, to the Italian National Committee, and to their Italian hosts generally, for the many courtesies and entertainments received by the members during their very pleasant stay at Turin. One of the many such entertainments was a dinner to the delegates on the summit of the hill "La Superga," about 400 metres above the city and some 10 kilometres to the north. The view of the Piedmontese Alps so obtained, by the light of sunset, above the intervening plain, was something never to be forgotten.

The American delegation consisted of H. B. Brooks, Gano Dunn, G. Faccioli, R. O. Heinrich, A. E. Kennelly, C. O. Mailloux, C. H. Sharp, E. Thomson, and Philip Torchio. This delegation was also separately entertained at a luncheon given by the Italian committee.

As a whole, the Congress was a great success, to which the prevailing fine and pleasant weather lent much aid. The Turin Exposition also added very notably to the interest of the meeting.

CORRECTION.

"THE Coefficient of Expansion of Tar," by John Morris Weiss," vol. clxxii, page 277,

"Specific gravity: $t°/t° = \frac{c - a}{(b - a) - (d - a)}$"

should read:

"Specific gravity: $t°/t° = \frac{c - a}{(b - a) - (d - c)}$"

Unsolved Problems in Electro-plating. G. B. HOGABOOM. (*Sci. Amer. Sup.*, 1846, 320.)—The problems most desired to be solved are: An electrolyte that will remove the fire-scale from brass; one that will produce a bright or a matte surface in place of using the present acid dips; an electric cleaner that will saponify the grease and dissolve it instead of drawing it to the top, whence it has to be constantly removed to prevent it adhering again to the work as the latter is removed from the solution; a heavy deposit of lead on the inside of iron pipes to prevent rapid corrosion; a method of coating electrogalvanized iron or steel with decorative metals without destroying the rust-resisting properties of the zinc; an alkaline nickel-silver solution that can be worked with a low voltage; a method of etching steel without destroying a resistance film of gelatine. Some alkaline substance to replace potassium cyanide would be universally welcomed.

Process for Increasing the Efficiency of Titanium. T. GOLDSCHMIDT. (*Ger. Pat.* 235, 461, 1909.)—In refining iron or steel by the addition of ferro-titanium it has not been found possible to attain good results with alloys containing more than 10 to 15 per cent. of titanium. However, if aluminum be added as a third component to the alloys, much richer titanium alloys can be used. Especially good results have been obtained with an alloy containing 24 to 25 per cent. of titanium and 3 per cent. of aluminum.

A Physical Interpretation of Non-Compensated Heat. L. DÉCOINTRE. (*Mon. Scient.*, lxxv, 551.)—It has been previously shown that the non-compensated heat disengaged in a reaction in which there is no such phenomenon as electrical conduction, ionization or atomic disaggregation may be identified with the *Siemens heat* which accompanies the electrification of the volume elements of the system. For each volume element this heat can be expressed by the sum of the terms proportional to the squares of the speeds of the sensible, independent reactions. It disappears when these speeds are infinitesimally small or zero. To generalize this interpretation of non-compensated heat it must first be observed that the electrification of a volume element results actually from the electrification of the atoms that it includes. This *Siemens heat*, then, must be applied to the electrification of the atoms. If the electronic point (considering the atom as an assemblage of electrons) is admitted, the electrification of an atom must be recognized as intrinsically caused by a certain deformation of the atomic edifice, a deformation to which the *Siemens heat* is to be attributed. This hypothesis may be expressed by saying that "every reaction accomplished with a finite speed is accompanied by a disengagement of heat proportional to the square of the speed of the reaction." As a further step by *Siemens heat* will be meant that heat of atomic deformation that will represent the non-compensated heat disengaged in every transformation not accompanied by conduction, by ionization or by atomic disintegration. If the preceding hypothesis is accepted, then it must be admitted that "the loss of an electron is always immediately followed (and, moreover, generally preceded) by a disengagement of *Siemens heat*." Similar reasoning seems applicable to the finite changes which accompany either the recombination of a negative electron with a positive atom, or the formation, the rupture and re-combination of the ions, or the splitting up of an atom into several others with or without the simultaneous liberation of ions and electrons.

Hence the production of *Siemens heat* appears to be a very general fact; and, moreover, it appears that under any circumstances it can be identified with the non-compensated heat of thermodynamics.

It seems difficult, if not impossible, to support this hypothesis by any demonstration or general verification. All that can be done, apparently, is to ascertain in each particular case whether it can be reconciled to the facts.

Boric Acid in Nickel-Plating. ANON. (*Brass World*, vii, 9, 330.)—The use of a large amount of boric acid in a nickel-plating solution is found to be advantageous. The nickel deposit is whiter and brighter than when a smaller amount is used, and the pitting is reduced. About 5 ounces of boric acid to 1 gallon of nickel solution are found suitable.

FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, October 18, 1911.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 18, 1911.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership since last report, 10.

The amendment to the By-laws relating to the election of the Board of Trustees, presented at the September meeting, was unanimously adopted.

Following the meeting of the Institute for the transaction of this business, a joint meeting was held with the American Society of Mechanical Engineers, Mr. Walton Clark, President of the Institute, and Mr. T. C. McBride, Chairman of the Philadelphia Section, jointly presiding, at which an important paper on "The Practical Application of Scientific Management to Railway Operation" was read by Mr. Wilson E. Symons, of Chicago. Mr. Symons dealt exhaustively with the subject of railway economics and the practical application of scientific methods to railway work, especially in the repair and motive power departments of railroads.

An interesting discussion followed the reading of the paper, in which the following gentlemen took part: Messrs. Webb C. Ball, Cleveland, O.; T. H. Clarke, Baltimore, Md.; A. L. Conrad, Chicago, Ill.; Harrington Emerson, New York City; Frank B. Gilbreth, New York City; George R. Henderson, Philadelphia; B. B. Milner, Wilmington, Del.; James Shirley Eaton, New York City; Charles Day, Philadelphia; Walter V. Turner, Pittsburgh, Pa., and S. M. Vauclain, Philadelphia.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of proceedings of the Stated Meeting held Wednesday, October 4, 1911.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 4, 1911.

DR. GEORGE A. HOADLEY *in the Chair.*

The following reports were presented for first reading:

No. 2472.—Minnick's Concrete Piles. Advisory. Adopted.

No. 2499.—Santo Vacuum Cleaner.

No. 2506.—Sherardizing Metallic Surfaces.

The following was presented for final action:

No. 2477.—Granbery's Stadia Rod. Referred back to Subcommittee.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Photography and Microscopy.—The first meeting of the season was held in the hall of the Institute on Thursday, October 5, 1911, at 8 P.M., with Dr. Henry Leffmann in the Chair. Three hundred members and visitors were present, including a large number of professional photographers.

Mr. G. Dietz, of the Multispeed Shutter Company, of New York, delivered an instructive and entertaining lecture on "High-Speed Photography," especially in connection with an electric flashlight attachment, enabling the operator to manipulate the shutter and flash simultaneously, producing a picture with an exposure as brief as 1/2000 of a second. He explained the mechanism of the shutter in detail, dwelling on the reasons why such a construction should be capable of great speed, permitting one to take high-speed photographs at night.

Some pictures taken by Mr. Jennings in daylight showed a sharply-defined baseball in flight between the bat and first base.

Many experiments were made, the negatives hastily developed, lantern slides made from the still wet plate and shown on the screen, illustrating the subject. The times of the exposures were not tested, but the rapidity was so great as to give a sharp negative from the fluttering wings of two chickens thrown in the air. An athlete jumping over a table was caught in the air over the table and sharply defined, while with an ordinary flash the man was shown as an unrecognizable smudge. Several portraits and groups were taken in 1/200 of a second.

The speaker explained fractional development, by which the exposed plate is first treated with reducer and then with the alkaline solution, suggesting the following formula, which may be modified so as to produce soft or hard effects, as desired:

SOLUTION 1.

30 ounces water.
2 drachms edinol.
2 drachms hydroquinone.
2 ounces sulphite, dry.

SOLUTION 2.

30 ounces water.
2 ounces carbonate of soda, dry.

Temperature, 65 to 70°.
Plates, 1¼ minutes in each.
Films, 1 minute in each.

Adjourned.

J. W. RIDPATH,
Secretary.

Electrical Section.—A joint meeting of this Section and the Philadelphia Section of the American Institute of Electrical Engineers was held on Thursday evening, October 12th.

The meeting was called to order by President Walton Clark, who invited Mr. H. C. Snook, Chairman of the Philadelphia Section of the American Institute of Electrical Engineers, to take the Chair.

Major George Owen Squier, of the Signal Corps, U. S. Army, was then introduced, and presented an interesting communication on "Electrical Methods of Intercommunication for Military Purposes."

The construction of telephone and telegraphic lines and cable laying done by the Signal Corps in the Philippine Islands, Porto Rico, Alaska, and elsewhere were described; range finding, signalling, and distant control of fire were also explained.

The subject was fully illustrated by numerous lantern slides made in the field.

By special request, at the close of the lecture, Major Squier also described his recently-developed system of multiplex telephony.

In the discussion which followed the paper Drs. Goodspeed, Northrup, and others participated.

Adjourned.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

Elections to Membership.

RESIDENT.

MR. FREDERIC ROSENGARTEN, Ninth and Parrish Sts., Philadelphia.
MR. WM. J. WALSH, care Fayette R. Plumb, Bridesburg, Philadelphia.
MR. ALBERT G. PETERKIN, care Benzol Products Company, Frankford, Philadelphia.

NON-RESIDENT.

MR. GUSTAV DIETZ, 317 East Thirty-fourth St., New York City.
MAJOR GEORGE OWEN SQUIER, Signal Corps, U. S. Army, Washington, D. C.
MR. JOHN STONE STONE, 31 State St., Boston, Mass.
MR. ANGUS KENNETH MILLER, 85 Clinton St., Brooklyn, N. Y.
MR. ROBERT ROWELL ABBOTT, Peerless Motor Car Company, Cleveland, Ohio.

ASSOCIATE.

MR. CHARLES WILLIAM SAXE, Newport Water Works, Newport, R. I.

Changes of Address.

MR. GANO DUNN, 117 West Fifty-eighth St., New York City.
MR. E. E. KELLER, Penobscot Building, Detroit, Mich.
DR. MORTON G. LLOYD, 319 South Oak Park Ave., Oak Park, Ill.
MR. E. F. MASON, Pennsylvania Railroad, Altoona, Pa.
MR. SOMMERS N. SMITH, 1744 North Sixteenth St., Philadelphia, Pa.

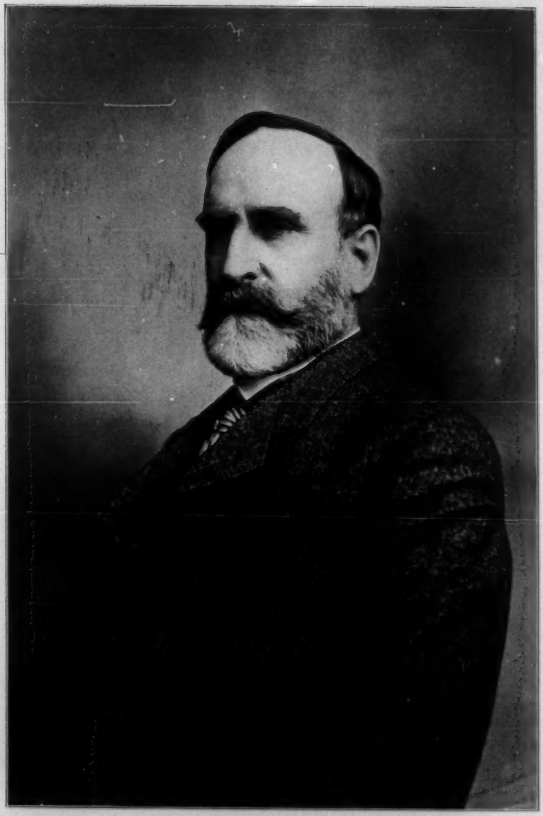
NECROLOGY.

James Christie, 3d Vice-President of the Franklin Institute, passed away at his summer home in Atlantic City on August 24th, within a few days of the 71st anniversary of his birth. He was the son of Thomas H. and Elizabeth Holmes Christie, born August 28, 1840, at the homestead of the family near Ottawa, Canada, where his grandfather, a native of Scotland, had settled on emigrating to America. Such education as was afforded him by the public schools of his native place he supplemented by reading and by acquiring a larger knowledge of French than he had learned in the *patois* of his French-Canadian comrades. His favorite theme from boyhood was Mechanics, and, having trained himself to proficiency in mechanical drawing, he went to Detroit in his 18th year and found employment as draughtsman in a machine shop. Not content with the training of the draughting-room, he widened his experience by working at intervals as journeyman machinist, and by the time he was twenty-three he had already demonstrated his fitness and efficiency in his chosen calling. He was employed in the extension of the Iron Mountain Railroad in Missouri, but, this enterprise becoming stalled by the progress of the Civil War, he found an opening for his talents in the then already widely reputed iron works of the I. P. Morris Company, of Port Richmond, Philadelphia. Here he met a number of men with whom he afterwards became associated in the Franklin Institute, including his subsequent fellow-member of the Committee on Science and Arts, the late John W. Cooper; his venerable predecessor in the vice-presidency of the Institute, the late Washington Jones, and his colleague in the City Councils of Philadelphia, the late John Hartman.

His four years' service at the I. P. Morris Iron Works was interrupted by his response to the call of his adopted country for volunteers to stem the tide of the Confederate invasion of Pennsylvania in 1863, but the decisive result of that campaign soon permitted him to resume the work for which his talents so specially fitted him.

In 1865 Mr. Christie joined with Henry Lewis Butler, of Phillipsburg, N. J., in a partnership to carry on a foundry and machine works in that city. In the succeeding years we find him taking an active part in the public affairs of Phillipsburg, first as a member of the Town Council and later, in 1874, as Mayor of the city. His record in that capacity, like that of his more recent political activity in Philadelphia, is that of a reformer in politics and an unselfish administrator of public as well as of private trusts.

In 1876, having become widely reputed as a builder of iron bridges and as an industrial organizer, Mr. Christie was called to aid in the reorganization and upbuilding of the Pencoyd Iron Works of A. and P. Roberts & Company, of Philadelphia. Here his abilities found full sway. He took upon himself, as chief mechanical engineer of the works, to increase the efficiency of the plant by what has now come to be known as "scientific management." He reorganized the working forces of the establishment



JAMES CHRISTIE
1840–1911

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to the end in view, introduced new methods of procedure whereby waste of time was avoided, and added new appliances, many of them devised by himself, whereby the output was at once lessened in cost and improved in quality. The success of Mr. Christie's methods in this undertaking became manifest in the rapid growth of the Pencoyd Works from that of a concern of minor standing to that of one of the most important factors in the bridge-building industry of the country. When, in 1899, that industry was further reorganized by the combination known as the American Bridge Company, of which the Pencoyd Works became a part, James Christie was retained as chief mechanical engineer and was given the task of laying out the great bridge-building plant located at Ambridge, Pa., on the Ohio River, the largest establishment of the kind now extant. His connection with the American Bridge Company continued until 1905, when he resigned and practically retired from active work.

In the midst of his successful prosecution of the art of bridge building James Christie did not omit to contribute largely to its science as well. Among these contributions may be mentioned particularly his treatise entitled "Experiments on the Strength of Wrought Iron Struts," a record of his researches in this direction at the Pencoyd Works. This paper, published in 1884, centred the attention of the engineering world as an exhaustive treatise on a subject of prime technical importance, and remains to this day a standard exposition of its subject matter. For this work the American Society of Civil Engineers awarded Mr. Christie the Norman medal.

While never ceasing his efforts to promote the interests of his profession, James Christie extended his activities into the larger field of general science as well. He became a member of the Franklin Institute in 1885, and from that time to his death he took a prominent part in its proceedings. He was to the last a member of the Committee on Science and Arts, its chairman in 1897, and his work in that connection is embodied in numerous reports of that committee published in the JOURNAL of the Institute. In addition to his work on that committee, Mr. Christie gave unremitting service to the Institute as a member of its Board of Managers, and as chairman of the committee charged with arranging the programme of its meetings. He was also a member of the Publication Committee, and served at intervals on each of the other standing committees of the Institute. In 1909, after the death of the late Secretary of the Institute, Dr. Wahl, Mr. Christie voluntarily took up the duties of that office and gave valuable service in that capacity. In 1911 he was elected Vice-President of the Institute in succession to the late Washington Jones, and so continued his usefulness to the last.

Besides his activities at the Institute, Mr. Christie took a leading part in the work of the Engineers' Club of Philadelphia, of which he was one of the earliest as well as one of the most ardent members. He was accorded the unusual honor of being twice chosen as president of that organization, and occupied that office until the time of his death. He was a Fellow of the American Association for the Advancement of Science, a member of the American Philosophical Society, of the American Society

of Civil Engineers, of the American Society of Mechanical Engineers, and of the G. A. R.

In the midst of his multifarious activities James Christie yet found time to give unselfish service to the cause of communal advancement. Besides serving as member of Select Council of Philadelphia from 1907 to 1910, as one of the few who gained election on an issue of municipal reform, he took an earnest part in the educational activities of his section of the city. He was also for a time a director of one of the local street railway lines.

James Christie was a most genial example of that not always genial genus, the "self-made man." His characteristics of forceful ability and innate modesty, of deep earnestness and refined good humor, of high ideals and practical common sense, combined to make him what he was, a leader in his profession and an efficient and welcome co-worker in all the other fields of his activity.

LOUIS E. LEVY,
JAMES M. DODGE,
E. H. SANBORN.

Mr. Cyrus Chambers, Jr., Overbrook, Pa., was born at Kennett Square, Pa., December 6, 1833, and died, after a brief illness, on July 9, 1911.

His inclination toward mechanical pursuits manifested itself early in life, and the many machines and other devices which he made while a boy attracted considerable attention.

A miniature high-pressure steam engine, composed of 150 pieces of gold and silver and weighing when completed less than half an ounce, was one of his achievements.

His earliest invention of note was a paper-folding machine for books and newspapers. This was put into commercial use in 1857 and led to the establishment of the firm known as Chambers Brothers & Company.

In 1861 Mr. Chambers manufactured and put upon the market a sewing machine which became quite popular, large numbers being sold in a short time.

He devoted much attention to the study of brickmaking, and the Chambers brickmaking machine has been in successful use for more than half a century. The first machine of its kind was erected at Pea Shore, New Jersey, early in the sixties, and turned out about forty bricks per minute. After forty-five years the machine is still in operation, and with the later improvements which have been added from time to time it now produces about forty thousand bricks per day.

Mr. Chambers became a member of the Institute in 1856, and for a number of years was active on various committees. He served several terms on the Committee on Science and the Arts, from 1876 to 1890 was a member of the Board of Managers, and during the past fifteen years he had been one of the Trustees.

Major James C. Brooks, whose death occurred at Philadelphia on July 18, 1911, was born in New Albany, Ind., in 1843.

At the outbreak of the Civil War he entered the Union Army, and served with distinction, attaining the rank of Major.

After the close of the war, Major Brooks entered mercantile life, and eventually became associated with the firm of William Sellers & Company, of Philadelphia, machine tool manufacturers. Later he became a partner in the firm.

In the year 1887 he was asked to take the office of President of the Southwark Foundry and Machine Company, of Philadelphia, builders of engines and other heavy machinery, which position he held until the time of his death.

Under his guidance this company became a leader in the class of work it was doing in the United States. The plant was enlarged, and the business grew to such proportions that in the course of the next five years its capacity was more than doubled, with the establishment of a name and reputation that was highly regarded not only in the United States but in Great Britain and the Continent of Europe.

He had studied with much care the early development of the iron and steel industry, and through his persistent efforts the Southwark Company designed an improved type of blast furnace blowing engine that has been used with great success throughout the civilized world where such industry is carried on.

Major Brooks was a director of the Franklin National Bank, the National Bank of the Northern Liberties, the Philadelphia Trust, Safe Deposit and Insurance Company, and a manager of the Western Saving Fund Society.

He became a member of the Franklin Institute in 1868, and during the past six years served as one of its Trustees.

Alexander Krumbhaar, who died at his residence in Wynnewood, Pa., on August 14, 1911, was the son of Lewis and Sophia Ramsay Krumbhaar, and was born in Philadelphia on July 27, 1842. His father was a member of the Franklin Institute, having joined in 1848. His son Alexander became a member in 1868, and was elected to the Board of Managers in 1898, and up to the time of his death served the best interests of the Institute by his intelligent and conscientious work. For many years he acted as chairman of the Membership Committee, and in connection with the duties of that office established many of the friendly relations existing to-day with some of the large manufacturing establishments in the city.

At the breaking out of the Civil War, in 1861, Alexander Krumbhaar, although a lad of but eighteen years of age, was chosen as an assistant by Major G. D. Ramsay, who was commandant of the Washington Arsenal. His thoroughness and ability were soon recognized, and the Military Storekeeper at the arsenal practically relied upon him for the delivery of arms, accoutrements, and ammunition for the infantry, cavalry, and artillery of the regular and volunteer army, and thus he practically outfitted the then Army of the Potomac with such supplies.

On the promotion of Major Ramsay to be Chief of Ordnance and to

the title of Major-General, he was succeeded by Major Stephen V. Benet, who urged Alexander Krumbhaar to remain with him at the Washington Arsenal, and subsequently, in 1864, when Major Benet was ordered to New York in connection with ordnance duty, he applied for and took him as his chief assistant. He was succeeded in the New York work by Major Benton, of the Ordnance Corps, with whom Alexander Krumbhaar remained. Colonel Benet, shortly after taking command of Frankford Arsenal, applied for Alexander Krumbhaar as his assistant, and, much against the wishes of Major Benton, the transfer was made. Colonel Benet remained at the Frankford Arsenal for several years, being ably assisted in his work by Alexander Krumbhaar, and shortly after his leaving to become General and Chief of the Ordnance Corps, with headquarters at Washington, Alexander Krumbhaar resigned and returned to private life and went into the business of manufacturing hand-made files. He continued this business for a number of years, eventually retiring to become interested in corporation work. His early military association prompted him to join the National Guards of Pennsylvania, and on September 9, 1878, he received his appointment as Major and Ordnance Officer of the First Brigade. He was reappointed on September 10, 1883, and on October 27th of the same year was promoted to Lieutenant-Colonel, with the duties of Assistant Adjutant-General. On June 3, 1887, he was appointed on the General Headquarters staff, still retaining the duties of Assistant Adjutant-General, and reappointed on February 2, 1891. In the early part of 1892 he filled the duties of Active Adjutant-General, and on February 15, 1895, was placed on the retired list.

General George R. Snowden, now on the retired list, but for many years in command of the First Brigade, eulogized Alexander Krumbhaar as follows: "His death is a great loss to me, for I highly esteemed him as a man of character and ability, worth and integrity. When together so long in the military service I relied constantly and with a firm assurance, gained by experience and observation, on his knowledge, capacity, energy, attention, and, in fact, all the qualities which go to make up worth and distinction. He was one of the most useful and valuable officers ever in the National Guard, a fact, it is a satisfaction to know, generally, I may say universally, recognized. He was frank, open, sincere, not afraid or, indeed, reluctant to express his opinion—and he always had one, and that clear and intelligent—on any subject brought to his attention."

Alexander Krumbhaar was of strong, marked personality and of the highest integrity, having a high sense of justice and fairness for his fellow-men. His sterling character was readily recognized by those with whom he came in contact. This, combined with a kindly and courteous disposition, endeared him to all who knew him.

LAWRENCE T. PAUL,
A. C. HARRISON,
COLEMAN SELLERS, JR.

Mr. J. Walter Ruddach, Jenkintown, Pa.
Mr. Charles J. Hughes, Jr.

LIBRARY NOTES.

Purchases.

BUNNELL, S. H.—Cost-keeping for Manufacturing Plants.
ARRHENIUS, S.—Theorien der chemie.
ARRHENIUS, S.—Immunochemie.
ARRHENIUS, S.—Das Werden der Welten.
ARRHENIUS, S.—Die Vorstellung vom Weltgebäude.
BUCKLEY, R. B.—The Design of Channels for Irrigation.
SCHNEIDER, N. H.—Electric Light for the Farm.
NIELSEN, T.—Calculation of Columns.
ZAHN, A. F.—Aerial Navigation.
EVANS, H. A.—Cost-keeping and Scientific Management.
LOUIS, H.—Metallurgy of Tin.

Gifts.

U. S. Commissioner of Labor, 24th Annual Report, 1909, Volume 2. Washington, 1911. (From the Commerce and Labor Department.)

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Jefferson Physical Laboratory, Contributions, Volume 8, 1910. Cambridge, Mass., n. d. (From the Laboratory.)

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Australia Commonwealth, Official Year Book, 1911. Melbourne, n. d. (From the Commonwealth Statistician.)

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Pennsylvania State Railroad Commission. In the matter of the complaints against the Philadelphia Rapid Transit Company. Report to the Commission by Ford, Bacon and Davis. Two volumes. 1911. (From R. D. Jenks, Esq.)

Chicago Mayor's Annual Message and 35th Annual Report of the Department of Public Works for 1910. Chicago, n. d. (From the Department.)

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Pennsylvania Department of Mines, Report for 1909. Part I, Anthracite. Harrisburg, 1910. (From the State Library.)

Pennsylvania Department of Internal Affairs, Annual Report for 1909–1910. Part 4, Rail-Roads, Canals, Telegraphs and Telephones. Harrisburg, 1911. (From the State Library.)

Pennsylvania State Railroad Commission, Report for 1910. Harrisburg, 1911. (From the State Library.)

Pennsylvania Department of Fisheries, Report for 1909, 1910. Harrisburg, 1911. (From the State Library.)

Thompson, Slason. Railway Library, 1910. Chicago, 1911. (From the Editor.)

New South Wales, Vital Statistics for 1910. Sydney, 1911. (From the Government Statistician.)

BOOK NOTICES.

CARNEGIE INSTITUTION OF WASHINGTON, PUBLICATIONS. No. 54. Bailey Willis, Charles D. Walcott, and others. "Research in China." In three volumes and atlas.

Vol. 1 in two parts $8.00

Part I. Descriptive Geology; by Bailey Willis, Eliot Blackwelder, and R. H. Sargent. Quarto, pages xiv + 353 + xvi, plates I–LI, 65 text figures.

Part II. Petrography and Zoology; by Eliot Blackwelder. Syllabary for Transcription of Chinese Sounds; by Friedrich Hirth. Quarto, pages vi + 355–528 + xvii–xxiv, plates LII–LXII (including 6 plates of birds colored to life).

Atlas. By Bailey Willis, Eliot Blackwelder, and R. H. Sargent. Folio. 42 maps and 21 other illustrations $7.00

Vol. 2. Systematic Geology. By Bailey Willis. Quarto, v + 133 + v pages, 8 plates $2.00

Vol. 3. Paleontology. By Charles D. Walcott, Stuart Weller, and George H. Girty. Quarto ..... In preparation

Volume I, Part I, contains observations relating to the geology of northeastern, northern, and central China (Shan-tung, Chi-li, Shan-si, and Shen-si). The treatment is primarily by districts, and under each district the terranes observed are described in order from older to younger. The nature and succession of strata, the fossils, and the structure of each terrane are discussed. The terranes observed may be enumerated as follows: Pre-Cambrian, Cambrian, Ordovician, Devono-Silurian (in central China only), Carboniferous, Permian (?), Jurassic, and Quaternary. The principal contributors to knowledge relate to the Pre-Cambrian, the stratigraphy and fossils of the Cambrian, and the history of the Quaternary. The last named comprises an analysis of the mountain forms in terms of uplift and erosion and a discussion of the loess. A unique feature is the account of an early Cambrian tillite or glacial till, which underlies the Cambrian limestone of the Yang-tzi valley. The volume is profusely illustrated with photographs of the scenery of the mountain districts of Chi-li, Shan-si (the land of the loess), and Shen-si.

The atlas contains two route maps, 20 topographic maps, and 20 identical geologic maps. The topographic maps represent the features along and adjacent to the route on a scale of 1:125000, with 100-foot contours. They are based on plane-table surveys and the forms of the land were stretched expressively in contours on the spot.

Vol. I, Part II, includes three special reports which are subsidiary to the general treatment of the geological observations in Part I of the same volume.

The first and largest section contains a description of the varieties of igneous, metamorphic, and sedimentary rocks collected by the expedition in China. All of these specimens come from northern China, the majority of them being from Shan-tung, western Chi-li, eastern Shan-si, and southern Shen-si. The collection comprises typical representatives of the geological systems from Archean to Mesozoic. Of special importance is the description and interpretation of the varied oolitic and conglomeratic limestones, found in the Cambrian terrane.

The second section, dealing with zoological observations of the party, includes an annotated list of the amphibians, reptiles, and birds observed. About 130 species of birds are noted, and of these six of the least known are illustrated by beautiful colored plates.

The last section contains a syllabary of Chinese sounds, prepared by Professor Hirth, of Columbia University. The orthography recommended by the author is compared in tabular arrangement with that of Williams and Wade, and all are referred to the corresponding Chinese ideographs.

Volume II treats of the same material as Volume I, but from the standpoint of systematic continental history. Repetition has been avoided so far as is consistent with the general subject. The subject-matter of this volume is classified primarily according to geologic eras of periods, and secondarily by broad areas, of which China proper is the central region. Each chapter treats of the geographic condition of southeastern Asia during a particular age, and the successive chapters trace the sequence of changes from age to age. Only the great events of continental history are distinguish-

able on the basis of existing knowledge, but they suffice to show that the present continent is an aggregation of land masses which, from time to time, have been forced into union with one another. This study of Asia has been carried on with comparative studies of North America and Europe, and has led to theoretical views regarding continental structure and development which have a broad application. They are briefly stated in a closing chapter.

PUBLICATIONS RECEIVED.

Direct and Alternating Current Manual, with Directions for Testing and a Discussion of the Theory of Electrical Apparatus. By Frederick Bedell, Ph.D., assisted by Clarence A. Pierce, Ph.D. 360 pages, illustrations, 8vo. New York, D. Van Nostrand Co., 1911. Price, $2 net.

A pocket medical dictionary, giving the pronunciation and definition of the principal words used in medicine and the collateral sciences, including very complete tables of the arteries, muscles, nerves, bacteria, bacilli, micrococci, spirilla and thermometric scales, ... By George M. Gould, A.M., M.D. Sixth edition, revised and enlarged. 1005 pages, 16mo. Philadelphia, P. Blakiston's Son & Co., 1911. Price, in leather, $1 net.

The Technical Analysis of Brass and the Non-ferrous Alloys. By William Benham Price and Richard K. Meade. First edition. 267 pages, illustrations, 12mo. New York, John Wiley & Sons, 1911. Price, $2 net.

Electro-analysis. By Edgar F. Smith, Blanchard Professor of Chemistry, University of Pennsylvania. Fifth edition, revised and enlarged. 332 pages, illustrations, 12mo. Philadelphia, P. Blakiston's Son & Co., 1911. Price, in leather, $2.50 net.

Essai sur une méthode de comptabilité des chemins de fer par Gustave Pereire. Premiere partie. 132 pages, quarto. Paris, Gauthier-Villars, 1911.

University of Illinois Bulletin. Water Survey Series No. 8. Chemical and Biological Survey of the Waters of Illinois. Report for 1909 and 1910. Edward Bartow, Director. 148 pages, illustrations, maps, 8vo. Urbana, University, 1911.

Ontario Bureau of Mines. Twentieth annual report, 1911, being volume xx, part 1. 301 pages, illustrations, plates, maps, 8vo. Toronto, King's printer, 1911.

Instructions for Experiments in Laboratory for Testing Materials, Purdue University. By W. Kendrick Hatt, professor of civil engineering and director of laboratory for testing materials, and H. H. Schofield, assistant professor in laboratory for testing materials. 72 pages, illustrations, 8vo. Lafayette, Ind. Authors, 1911.

U. S. Department of Agriculture, Forest Service, Bulletin 99. Use of Commercial Woods of the United States: II. Pines. By William L. Hall, assistant forester, and Hu Maxwell, expert. 96 pages, 8vo. Washington, Government Printing Office, 1911.

Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires. By George O. Squier. A paper presented at the 28th

Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911. 48 pages, illustrations, 8vo. Reprinted from the Proceedings for May, 1911.

American Mining Congress, October 24–28. Announcement of meeting, programme and speakers. 30 pages, illustrations, 8vo. Chicago, 1911.

National Association of Cotton Manufacturers. Fourteen pamphlets, advance copies of papers presented at the semi-annual meeting held at Manchester, Vt., September 27–30, 1911. Boston, Association, 1911.

North Carolina Geological and Economic Survey. Economic Paper No. 22. Forest fires and their prevention, including forest fires in North Carolina during 1910. By J. S. Holmes, forester. 48 pages, 8vo. Raleigh, State printers, 1911.

U. S. Geological Survey. Water Supply Paper 239. The quality of the surface waters of Illinois. By W. D. Collins. Prepared in coöperation with the Illinois State Water Survey, the Illinois State Geological Survey, and the Engineering Experiment Station of the University of Illinois. 94 pages, plates, maps, 8vo. Washington, Government Printing Office, 1910.

Pennsylvania State College Bulletin. Winter Courses in Agriculture. 15 pages, illustrations, 8vo. State College, 1911.

U. S. Bureau of Standards. Circular No. 8. Testing of Thermometers. Second edition, revised and enlarged. 52 pages, illustrations, 8vo. Reprint No. 149. On the Constancy of the Sulphur Boiling Point. By C. W. Waidner, physicist, and G. K. Burgess, associate physicist. 4 pages, 8vo. Washington, Government, 1910–11.

State Employers' Liability (or Workmen's Compensation) Insurance. By Edson S. Lott, president, United States Casualty Company, New York. Read before the Liability Insurance Association at its annual meeting, Hotel Astor, New York, October 19, 1911. 15 pages, 8vo.

CURRENT TOPICS

The Properties of Mesothorium. O. HAHN. (*Chem. Zeit.*, xxxv, 845.)—Mesothorium is the first disintegration product of thorium. It is composed of two constituents, mesothorium I and mesothorium II, which latter gives off β- and γ- rays. By gradual disintegration mesothorium forms, first radio-thorium, then thorium X emanations and thorium A-B-C-D. Radio-thorium exists in equilibrium with the last four and emits α-, β- and γ-rays. The disintegration of mesothorium occurs with an increase of radio-activity. This increase, starting with pure mesothorium, would last about 3.2 years and would be followed by a slow decrease for 10 years, and a value half that of the original mesothorium is reached in 5.5 years. Technically-prepared mesothorium contains about 25 per cent. of radium, which greatly extends the period of decrease. It requires 1800 years to reduce the radio-activity of radium to one-half, and assuming that radio-activity is inversely proportional to the rate of disintegration, the radio-activity of mesothorium must be 300 times that of an equal weight of radium. As technically-prepared mesothorium has a radio-activity equal to that of pure radium bromide, and as it contains 25 per cent. of radium bromide, the remainder must consist of 0.25 per cent. of mesothorium and 74.75 per cent. of inactive substance. The author succeeded in separating the inactive substance, and obtaining a product whose radio-activity was nearly four times as great as that of an equal weight of pure radium bromide, but attempts at the further separation of the mesothorium and radium were unsuccessful, as the chemical properties of the two substances are similar. Pure mesothorium emits only β- and γ-rays, so that the α-rays in technically-prepared mesothorium are due to the presence of radium.

A New Electro-galvanizing Solution. E. F. KERN'S PATENT. (*Brass World*, vii, 9, 331.)—The ingredients are:

Water	1 gallon
Zinc chloride	1 pound
Sodium-aluminum chloride	5 ounces
Sodium chloride	4 ounces
Grape sugar	5 ounces

Requires a very high-current density with a very low voltage. With a current density of 20 ampères per square foot, only 0.55 to 0.66 voltage is required. A dense adherent deposit, free from zinc salt or zinc oxide, was obtained. A temperature of 100° F. is advisable.

Melting Metals with High-pressure Gas. U. S. CONSUL ALBERT HALSTEAD. (*Brass World*, vii, 9, 312.)—The use of high-pressure gas for melting metals is attracting great interest in England. No air blast is necessary, so a *reducing* flame is obtained, without noise, and the loss by oxidation is greatly reduced. In brass melting the loss of zinc is only 75 per cent. of the loss in coke furnaces; and there is no loss of copper. Foundry aluminum is melted at a cost of $1.46 per ton in the Birmingham gas department.

The New Mechanics. EDWIN TARRISSE. (*Amer. Mach.*, xxxv, 363.)—As has been repeatedly pointed out in France, the contrast between the so-called "New Mechanics" and the old mechanics, based on Newton's laws of motion, offers some interesting features. The new conceptions of the science of motion are not easily presented to the lay mind because of their entire novelty. The modern idea is that a constant force acting upon a moving body does not impart equal velocity in each successive second, but that the accelerative effect decreases as the velocity of the body increases, and finally reaches a limit that it cannot pass. This limit is the velocity of light. In other words, the inertia of matter increases with its velocity of translation, and becomes infinite when the velocity is equal to that of light. Another form of statement is that the mass of a material body increases with its velocity of movement, and that there can be no motion swifter than that of light; that is, about 186,330 miles per second.

The Escape of Gas from Coal. H. C. PORTER AND F. K. OVITZ. (*U. S. Bureau of Mines Technical Paper* No. 2, 1.)—Laboratory experiments made with certain American bituminous and semi-bituminous coals from dangerous mines showed that these coals liberate methane not only during mining but also for a long period afterwards. Taking the volume of coal as unity, about ¼ volume of methane escaped during crushing and ½ to 1½ volumes on continued exposure to air. The escape of methane was rapid at first, but ceased after 3 to 18 months. The reduction of the calorific value of the coal due to the loss of methane was very small. Such coals absorbed oxygen over a prolonged period at varying rates, without an equivalent formation of carbon-dioxide. The well-known influence of atmospheric pressure on the liberation of inflammable gases in mines is probably due to the pressure of reservoirs of these gases in the stratified rocks, and not to the presence of gases in the substance of the coal itself.

The Constitution of Water. J. DUCLAUX. (*Mon. Scient.*, lxxv, 555.)—According to Röntgen's hypothesis, water consists of molecules of ice (as a dissolved body); that is to say, the water is polymerized for one part, and the other part is an ideal liquid,

which cannot exist in the pure state without also partly polymerizing, which Sutherland has named *hydrol*, and which is formed of simpler molecules than those of ice. Therefore, water is a solution of ice in hydrol. In considering this hypothesis it must be admitted that the molecule of ice is $(H_2O)_3$. J. Duclaux studied this question by new methods and arrived at different conclusions. He found that ice polymerizes approximately as $(H_2O)_9$, M. Wt. 162, to $(H_2O)_{12}$, M. Wt. 216. These numbers were obtained by the study of the variation of the expansion of water with the pressure; if the variations of the compressibility with the temperature are calculated, the numbers found for the molecule of ice agree with the formulas $(H_2O)_8$, M. Wt. 108, and $(H_2O)_{23}$, M. Wt. 414. By combining the formula of expansion given by Röntgen for water:

$$V = a + bT + cT^2 + dT^3 \ldots . + KT^{-8} \frac{\alpha}{eT^3} + \frac{\beta}{T^2} + \frac{\gamma}{T} + \xi T,$$

the parabolic terms representing the expansion of hydrol, and the exponential terms the excess of the volume of ice dissolved over that which the hydrol would give in de-polymerizing alone, with those which the study of the specific heat gives, another method of determining the polymerization of ice is reached. This gives the molecule of ice as $(H_2O)_{12}$, M. Wt. 216.

Locomotive Cylinder Castings. ANON. (*Amer. Mach.*, xxxv, 320.)—According to *Railway and Locomotive Engineering*, the composition of cast iron for locomotive cylinder castings has been carefully estimated by mechanical engineers as follows: Graphitic carbon, 2.75 to 3.25 per cent.; silicon, 1.25 to 1.30; phosphorus, 0.50 to 0.80; combined carbon, 0.50 to 0.70; manganese, 0.30 to 0.60; and sulphur, 0.06 to 0.10 per cent. The presence of sulphur in an excessive degree is said to be one of the serious evils to be particularly guarded against in the selection of cast iron, while the proper mixture of silicon is also of the greatest importance.

Tests of Lubricating Grease. G. W. LEWIS. (*Amer. Mach.*, xxxv, 356.)—This is a valuable article for all users of lubricants. In brief it may be summarized as showing that the results of tests on a large number of greases give the coefficients of friction and rise in temperature of the bearings. There are also given several simple tests that can be made by the user to determine the character of the grease under consideration, *e.g.*, tests for acids, alkalies, volatile matter, filling, water and propensity to gum.

Loss in Coal Due to Storage. A. BEMENT. (*Chem. Eng.*, xii, 9.)—In experiments to find (*a*) change in heating power, (*b*) change in weight, (*c*) tendency to disintegrate by slacking, in certain Illinois coal when in storage, Springfield coal showed a loss in heat-

ing power of 0.93 per cent., loss in weight of 1.15 per cent.; central seam coal, 1.85 per cent. loss in heating power and 2.29 per cent. loss in weight; southern seam coal, 0.38 per cent. loss in heat-value and 0.11 per cent. gain in weight. Southern seam coal retained 87.84 per cent. in lump form; Springfield coal 35.49 per cent., and central seam coal 18.36 per cent. Stored under water, central lost 0.44 per cent. in heat-value and 0.35 per cent. in weight; southern gained 0.02 per cent. in heat-value and lost 0.81 per cent. in weight. All tests were for a period of one year.

Large Crane. ANON. (*Amer. Mach.*, XXXV, 210.)—The largest crane in the world has been recently erected at Govan, near Glasgow, on the river Clyde, for the Fairfield ship-yards. On slow gear the crane can elevate 200 tons extended 75 feet along the jib, and on quick gear it can carry a load of 100 tons at 133 feet. The stability of the crane is maintained by four large tubes, 15 feet in diameter at their bases, filled with concrete, and sunk 74 feet below ground.

Absorption Spectrum of Iodine and Bromine Vapor at High Temperatures. E. J. EVANS. (*Astro. Physic. Journal*, xxxii, 1 and 291.)—Iodine vapor at different pressures was heated in a quartz tube to various temperatures up to about 1300° C. and its absorption spectrum was studied by passing through it light from a carbon arc which was examined by means of a concave grating spectroscope of 1 mm. focus. The temperature at which the absorption spectrum vanishes increases with the increase of pressure. The degree of dissociation of the iodine vapor is high at these temperatures, and it is therefore assumed that the cause of the disappearance is that the monatomic molecules show no absorption for the visual spectrum, and that absorption is due to the diatomic molecules. The absorption spectrum of bromine vapor disappears at high temperatures, and the temperature of disappearance is increased by increase of pressure. The disappearance of the absorption lines is closely connected with the dissociation of the diatomic molecules, and can be explained on the hypothesis that the monatomic molecules produced by dissociation give no absorption spectrum within the limits λ 3500 to λ 6800.

Phellandrene Process for Extracting Copper. ANON. (*Chemist and Drug.*, July 29, 1911.)—This process was first used at Broken Hill, in New South Wales, but its use is now widely extended. The crushed and ground ore is mixed with water to a cream and 4 pounds of eucalyptus oil, containing phellandrene, are added to each ton of ore; the copper is collected by the phellandrene and this floats to the surface of the magma. The oil is then removed by distillation. The oils of eucalyptus containing phellandrene appear to be the only oils suitable for the purpose, and their

use for the extraction of copper has considerably enhanced their value. Inquiries for oils yielding phellandrene are now being made all over the Eastern States of Australia, and an increased production of these oils has resulted. The labor conditions are a great drawback to the eucalyptus oil industry as they are to the other industries.

The Kinetic Theory of Gases and the Realization of a Material Radiation of Thermal Origin. L. DUNOYER. (*Comptes Rendus*, clii, 592.)—The following experiment appears to afford evidence of the kinetic movements of molecules in a gas. A cylindrical tube is divided into three compartments by partitions perpendicular to the axis of the tube; these partitions are pierced by a small hole in their centres, forming diaphragms. The tube is fixed in a vertical position and a substance, non-volatile at the ordinary temperature, such as sodium, is placed in the lowest compartment, and then the tube is exhausted. The lowest portion is heated till the sodium vaporizes. The molecules of the vapor move in all directions in the lowest compartment with a mean velocity dependent on the temperature applied. Some of them traverse the lowest diaphragm; the majority strike the walls of the tube or the lower surface of the upper diaphragm, and deposit there. Some, however, pass through the hole in the second diaphragm. Among these molecules very few will collide, because their velocities are almost all in parallel directions, and since foreign gases are absent or negligible, these molecules continue on their straight course with a mean velocity of the order of 550 metres per second, if the sodium was heated to 400° C., until they strike the end of the tube. If an obstacle is in their path, a shadow will be formed or even an umbra and penumbra. No deposit is formed on the side walls of the upper compartment. This experiment appears to demonstrate the rectilineal propagation of something material; and further that this is not a mere turbulent jet of gas, but the propagation of particles in parallel straight lines.

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